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ON THE STABILITY AND STRENGTH OF THE STONE ARCH.

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THE theory of the stone arch has been so often discussed during the past few years that a new treatment of the subject may seem superfluous. Various methods of treatment have been proposed, differing greatly in the fundamental principles on which they rest, while in some those principles have not been clearly stated. Some authors treat the subject with the aid of statical principles alone, while others apply the theory of elasticity exactly as they would apply it to an arch of iron. It is believed that this latter method of treatment, while theoretically correct, is open to objections in practice, and that its results cannot be depended upon for absolute accuracy, while other methods are generally accompanied by an uncertainty, to dispel which various unscientific hypotheses have been proposed. Under these circumstances it may not be out of place to take up the subject once more, and to endeavor to show clearly the fundamental principles on which the stability and strength of arches depend. It is believed that the basis for a more satisfactory treatment of the arch than any heretofore proposed, is afforded by a theorem which was first demonstrated by Prof. Dr. Winkler, of Berlin—an authority well known in this country—and published in the "*Zeitschrift des Architekten und Ingenieur Vereins zu Hannover*" 1879, page 199, and that it enables us to arrive at a method of testing the stability and strength of stone arches, which is at least as accurate as any heretofore used, without being encumbered with any uncertainty. This method is at present the one perhaps more extensively used than any other, being, in fact, nothing more than the old method of endeavoring to construct a line of resistance within the middle third of the arch ring, but it is believed that the only satisfactory basis for that method yet proposed is offered by the theorem above referred to. Theorems somewhat similar have been at various times asserted without demonstration, and they will be referred to in the sequel. The bearing which they have on the theory of the arch has also been remarked, so that this article contains little new in itself. These various views and demonstrations have not, however, so far as the writer knows, been collected together into a succinct theory.

The stability and strength of any kind of an arch, of stone or of iron, depend upon the position of a certain line, called the *line of resistance*. Confining ourselves to the usual case in which the axis of the arch ring lies in a plane, in which plane also the outer forces act, the line of resistance will be a plane curve, and may be defined as the locus of the centers of pressure on each section perpendicular

to the plane of the outer forces, and (in general) to the axis of the arch ring. It may be constructed as follows: Supposing that on any section AB, at right angles to the axis, the real force acting: P, is known, in amount, direction, and point of application, S; then in order to find the real force P, acting on any other section CD, we compound P with the outer force F acting on the part ABDC of the arch, and the resultant of these forces is P_1. Its intersection S_1 with CD is the center of pressure on that joint, or the point through which the resultant of the stresses on that joint must pass. In making this construction for the stone arch it is usual to consider, not the whole arch, but a strip of it whose width is one foot, and the arch is thus composed of a series of these strips laid side by side, the section of each strip being a rectangle. The load being supposed

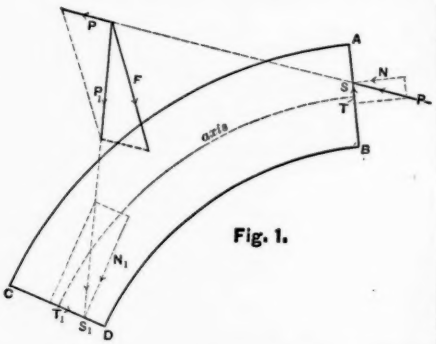


Fig. 1.

uniformly distributed over the whole width of the arch, it is only necessary to investigate the stability of one strip. With iron arches, which are built as a series of separate ribs, one rib, with its load, is considered. The line of resistance is the locus of the points S, S_1, etc., when the sections are taken infinitely near together, so that the line is a curve. The sections are generally taken normal to the axis of the arch ring (which is considered to lie in the plane of the paper) but in cases where there are well marked joints of separation between the pieces composing the arch—as in the stone arch, where the joints between the voussoirs form such dividing surfaces—these joints are taken as the sections used in finding the line of resistance.

From Fig. 1 it is clear that having given the force P on AB, we can find the force P, on any section CD, whether normal to the axis or not. We shall suppose, however, the joints to be normal to the axis of the arch ring.

If we resolve the forces P, P_1, and F, horizontally and vertically, P into V and H, P_1 into V_1 and H_1, F into V_{11} and H_{11}, then the condition that P_1 is the resultant of P and H is expressed by the equations

$$V_1 = V + V_{11};\ H_1 = H + H_{11}, \quad . \quad . \quad . \quad (1)$$

The state of stability and strength of any arch is deduced from the position of its line of resistance by the aid of the hypothesis of Navier, which supposes the normal component of the stress on any joint to vary uniformly from some line of no stress, called the neutral axis. The position of the neutral axis may be found for any given case with the aid of the theory of elasticity,* but in the case of the stone arch it will, under the assumptions made regarding the outer forces, always be perpendicular to the

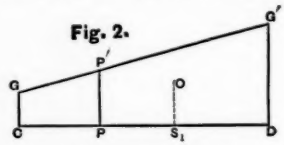


Fig. 2.

plane of the axis. If we resolve P_1, then, into two components, N_1 and T_1, N_1 acting through S_1 at right angles to CD, and T_1 along CD, and if we lay off at each point P of CD a line PP′ representing the intensity of the normal stress at P, all the points like P′ will lie in a plane which intersects CD in a line perpendicular to the plane of the paper. The area CD G′G will represent N_1, and if from the center of gravity O of that area we draw OS_1 at right angles to CD, P_1 will pass through S_1, or S_1 will be the center of pressure on CD. The distribution of T_1 over the section CD may be also found by the theory of elasticity, with the aid of some assumptions, but it is generally not done in discussing the stone arch.

Thus if we have given the form P acting on a given joint, the determination

* See an article by the writer "On a General Formula for the Normal Stress in Beams of Any Shape." VAN NOSTRAND'S MAGAZINE, July, 1880.

of the distribution of the normal stress over that joint is reduced to the problem of drawing the line GG′ so that the area GG′DC shall represent the normal component, N, of that force, and its center of gravity shall lie on the line of action of N. This problem may be solved in many ways. The following solution may perhaps serve to illustrate as well as any other the distribution of the stress: Let the rectangle CD D′C′ repre-

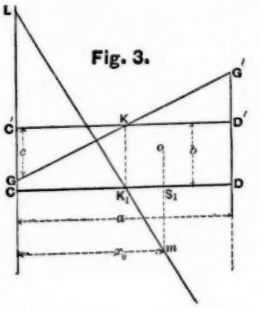


Fig. 3.

sent N, and let $CD=a : CC'=b$. Since the trapezoid CDG′G must represent N, it must equal CDD′C′, or GG′ must pass through K, the middle point of C′D′. Let $C'G=c$. If $CS_1=x_0$ we must have Nx_0 or $ba.x_0$=moment of GG′DC about C, or

$$ba.x_0=\frac{ba.a}{2}-\frac{a}{2}\cdot\frac{c}{2}\cdot\frac{a}{6}+\frac{a}{2}\cdot\frac{c}{2}\cdot\frac{5a}{6}.$$

Hence

$$bx_0=\frac{ba}{2}+\frac{ca}{6};\quad c=\frac{6b}{a}\cdot\left(x_0-\frac{a}{2}\right) \quad . \quad . \quad . \quad (2)$$

Writing this as a proportion,

$$c : 3b :: x_0-\frac{a}{2} : \frac{a}{2}.$$

Hence the following construction: Make $CL=3b=3CC'$, and draw LK_1 through the middle point of CD. OS_1 produced gives $S_1M=c$, which being laid off at C′G, GG′ may be drawn at once. For the similar triangles CLK_1 and K_1S_1M give $S_1M : CL :: K_1S_1 : CK_1$ or

$$c : 3b :: x_0-\frac{a}{2} : \frac{a}{2},$$

as required by eq. (2). From this construction we learn all that is necessary in regard to the connection between the stresses and the position of the line of resistance. The following cases may be distinguished:

1°. If $S_1K_1=o$; then $c=o$. Hence the stress is uniformly distributed.

2°. If $S_1D=\frac{1}{3}CD$; then $c=b$. Hence there is no stress at C, and that at D is represented by $2b$.

3°. If S_1 lies between the two positions just mentioned, there is a positive (compressive) stress on all parts of the joint.

4°. If $S_1D<\frac{1}{3}CD$; then $c>b$, hence there is a negative stress, or tension at C. The mortar of the joints is able to bear a certain tensile stress, but for safety it is generally assumed that it can bear none. Hence the stress will be distributed over a distance equal to three times S_1D, according to 2°, the remainder of the joint being without stress.

5°. If S_1 approaches near enough to the edge D, the stress at that edge will be greater than the crushing strength of the material.

6°. If S_1 falls outside of the joint it is clear that there can be no equilibrium, and the arch will fall—the mortar being supposed without tensile strength.

Hence the *condition of equilibrium* of an arch is: *the true line of resistance must fall within the arch ring at every point.*

A consideration of the crushing strength of the material makes the *condition of strength* take the following form: *The true line of resistance must not approach near enough to either edge of the arch ring to crush the stone at that edge.* The limit may be found as follows: Let s be the smallest value of S_1D. The stress is distributed over $3S_1D$ or $3s$, and the greatest stress, that at D, has the value $\frac{2N}{3s}$, or twice the mean pressure, and this must equal the crushing strength of the stone, C. Hence we have

$$\frac{2N}{3s}=C \text{ or } s=\frac{2N}{3C} \quad . \quad . \quad . \quad (3)$$

which enables us to find C when N is known.

In practice, it is advisable that the whole surface of each joint should be subject only to compression, in order that there may be no tendency for the

joints to open. This leads to the following condition, which may be considered the basis for the treatment of the arch: *The true line of resistance should everywhere lie within the middle third of the arch ring.*

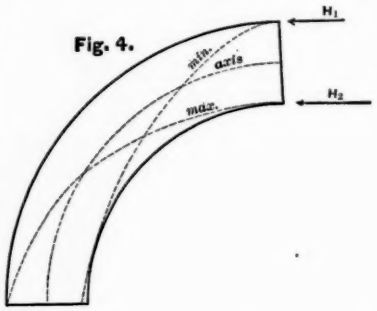
But whichever of the three conditions stated above be laid at the bottom of the method of treatment, it is clear that the stability and strength of the arch depend on the position of the *true* line of resistance. We have shown how to draw the line of resistance when the force acting on one joint is known. Suppose that force assumed, and the line of resistance drawn lying within certain limits. In general, other lines of resistance may be drawn within the assumed limits, and of all possible lines of resistance the true one must be found before any conclusions whatever can be drawn relating to the stability and strength of the construction—or at least, limits must be found within which the true line of resistance must be proved to lie.

Before proceeding further, it will be well to consider for a moment what outer forces may act upon the arch.

The outer forces may be vertical or inclined, the horizontal components of inclined forces being due to resistance of the spandrils, or to earth pressure. With regard to the latter, it does not exist in many cases, except in those of tunnel-arches, and arches under railroad embankments. It must of course be taken account of in investigating the stability of the arch. With regard to the former, however, opinion seems to be divided regarding the advisability of taking account of it, some authors neglecting it altogether, and some considering that it is capable of supplying the horizontal *thrust* necessary to sustain in equilibrium a linear arch parallel to the intrados of the proposed arch and similarly loaded. The resistance of the spandrils is an element of stability, and that it will act, as the arch ring tends to deform under the action of the loads to which it is subjected, is not to be denied. Its amount, however, cannot be determined, and will evidently depend upon the execution of the spandril walls and backing, the thickness of the joints, etc., and will increase as the deformation of the arch ring increases. In view of these facts, it is the opinion of the writer that it should be left out of account in investigating the stability, and that the arch should be constructed so as to be stable without its assistance. We shall refer to this point once more. In case no horizontal forces act on the arch ring, the horizontal component of the force acting on any joint is constant through the whole arch, while in cases where the outer forces are inclined, that component varies, as shown by equation (1).

Now suppose that, starting with a given force on a given joint, the line of resistance be drawn. By varying the assumed force, in amount, direction, and point of application, other lines of resistance may be drawn, and in general an infinite number of them may be constructed within the limits adopted. To determine which of these lines is the true one, various hypotheses have been made. Some writers have assumed that

Fig. 4.



one to be the true one which gives the smallest absolute pressure on any joint in the arch. Others have taken as the true one the one lying nearest to the middle line of the arch ring, that is, the one whose average distance from the middle line is the smallest. Others call in the aid of the "principle of least resistance," and declare that were the arch stones incompressible, that line of resistance would be the true one for which the horizontal component of the stress on any joint—and hence on each—is a minimum consistent with stability, and that the effect of the compressibility of the arch stones is simply to cause the line of resistance to retreat slightly within the arch ring at points where it would otherwise reach the edge. It is

not the intention to develop here the rinciple relating to lines of resistance with minimum and maximum horizontal thrust, but we will simply state that it may be easily proved that the line of resistance with the maximum horizontal thrust, which is possible without the corresponding line of resistance passing out of the arch ring, or the maximum line of resistance, as we shall call it, must touch the extrados at two points, and the intrados at one higher intermediate point, while the minimum line of resistance must in general touch the intrados at two points, and the extrados at one intermediate point.* These two lines deviate, then, as far from the axis of the arch as it is possible for them to do without passing outside of the arch ring. For symmetrical arch and loading, the lines of maximum and minimum horizontal thrust will have positions something as shown in the figure. By starting with the minimum line of resistance, with the thrust H_1, and by gradually increasing H_1 and lowering its point of application in the crown, we arrive at last at the maximum line of resistance. Both deviate as far as possible from the middle line of the arch ring—the axis—but in opposite directions, so that we know that in passing from one to the other, with some intermediate thrust and point of application at the crown, the corresponding line of resistance must have been on the whole nearer the axis than either the maximum or minimum line of resistance, and the same is true for unsymmetrical arch or load.

There seems, then, to be little unity of opinion among authorities regarding the position of the true line of resistance, although on its determination the whole theory of the arch depends. On considering the subject closely, however, it is clear that the line of resistance will have a fixed position, determined by the elasticity of the material. It is well known that this is the case with the iron arch, and between the iron arch and the stone arch there is no essential difference, so far as the theory is concerned. The effect of the elasticity of the material is not simply to move the line of resistance a little toward the axis of the arch ring at those points where it would, according to the principle of least resistance—which itself admits of dispute—touch the extrados or the intrados, but that effect can only be investigated mathematically, and it is not possible to say beforehand what it will be. The application to the stone arch of the principles of the mathematical theory of elasticity offers, it is true, great difficulties. We have here to do with a non-homogeneous elastic arch, an arch whose modulus of elasticity is not constant, but varies between that of stone and that of mortar; an arch, moreover, whose section and moment of inertia are, in many cases, not constant; and by a mode of construction often employed the arch and its abutments are made as one piece, and both must be considered together as forming one elastic rib. Further, the determination of the axis may offer some difficulty, for, the axis being defined as the locus of the centers of gravity of sections perpendicular to itself, these sections cannot be fixed in position until the axis is known, while the axis itself depends upon the position of the sections. The process of finding the axis is hence a tentative one. And the process of determining the line of resistance may also be a tentative one, on account of the fact that the sections are not exactly known. If a joint opens, only that surface on which the stress acts can be considered as forming the section, so that if we assume at first that all joints remain closed, and find that our resulting line of resistance in fact passes in some places out of the middle third of the arch ring, the process would have to be revised. But if the joints open, we encounter a new difficulty, for although only the bearing surface at each joint can be considered as the section at that point, it would obviously be incorrect to suppose the section to vary suddenly to that of the full arch ring; for although the methods of treatment of elastic arches of varying section do not require the section to vary continuously, yet were that not the case the

* A full discussion of the properties and construction of lines of resistance may be found in "Scheffler—Theorie der Gewölbe, Futtermauern, und eisernen Brücken—Braunschweig, 1857. Equations to the lines of resistance and their tangents, with some of their properties in "Dupuit—Traité de l'équilibre des voutes, et de la construction des ponts en maçonnerie—Paris, 1870." An account of Scheffler's investigations and results, with remarks on the application of the theory of elasticity to arches, in Cain, a practical theory of voussoir arches. New York. VAN NOSTRAND'S SCIENCE SERIES, Nos. 12 and 42," first published in this Magazine.

laws of elasticity on which those methods are based would probably not be exactly correct. How far the results obtained would be invalidated by the circumstance, we cannot say, but incline to the opinion that the effect would be very small. Again, the elastic treatment of the arch requires the sections to be perpendicular to the axis, while in many stone arches the joints lie obliquely. Further, a want of homogeneity of the mortar may be accompanied by serious effects; a small pebble of very hard stone might suffice to make the line of resistance pass through itself, acting, as it were, the part of a hinge on the joint where it occurs. The true position of the line of resistance would be further influenced by the action of the center, its rigidity, and the mode of loading it to prevent deformation, the method and rapidity of striking the centers, the yielding of the abutments, and so on. But, assuming that the mortar is homogeneous, that the joints are thin, and that disturbing elements are as far as possible eliminated, the line of resistance might be at least approximately determined, though it would be a tedious process. Nevertheless, as eminent an authority as Prof. Winkler advocates the elastic theory of the stone arch, and it is clear that theoretically it is the only theory leading to an accurate insight into the condition of any part of the arch, but the practical difficulties referred to above would be sufficient, it seems to the writer, to render the results for the most part illusory, which, as will be shown, much simpler methods can lead to correct results regarding the stability and strength of the construction. The application of the theory of elasticity to stone arches has, in fact, been considerably discussed in late years. The first mention of such a treatment of the arch occurs, so far as the writer knows, in Winkler's "Lehre von der Elasticität und Festigkeit," and since that work appeared various papers and works on the subject have been published, some of which are mentioned below.* Prof. Keck, the editor of the *"Zeitschr des Arch.-und Ing.-Ver zu Hannover,"* in a notice on the article of Perrodil, said that on account of the fact that the original stresses (stresses which the unloaded arch must be supposed to have) are not known, the application of the theory of elasticity is not correct, and the "rough method" which has hitherto been used is on the whole to be preferred. Méry (annales des ponts et chaussées, 1840) said, speaking of the true line of resistance, that it can only be determined "par des considerations plus on moins incertains sur les effets du tassement, Mais cette recherche n'est mullement necessaire, ainsi que l' on vient de le voir, pour être assurée de la solidité de la voûte." But this he does not prove satisfactorily. Prof. Cain (Theory of solid and braced elastic arches, VAN NOSTRAND'S MAGAZINE, NOV. 1879) also suggests the application of the theory of elasticity to arches, as leading to the most exact solution of the problem of their strength. He considers it unnecessary for testing their stability, since the arch "cannot fall until all of its cases of stability are exhausted." The writer is unable to see but that in order to be sure that the arch is stable, it is necessary to know the true line of resistance, just as much as to be sure that it is strong enough. It seems to him that Winkler's theorem is the basis of both strength and stability. Prof. Greene, in Part III. of his work on trusses and arches, applies the theory of elasticity to stone arches just as to iron arches. The results thus arrived at are approximately correct, but the process is a tedious one if it is applied rigidly, even based on the supposition of a homogeneous material and a constant section.

We have allowed ourselves to be drawn somewhat at length into the consideration of the application of the theory of elasticity to arches of stone, because it is a question now under discussion. We hope that the theorem which will follow, and which are derived from its principles, will suffice to show that it is not necessary to apply it in practice.

*Steiner—Allgemeine Bauzeitung, 1874—Uber Theorie der Bogenbrücken" (after Winkler's lectures).
Hübl—Allgem. Bauzeitung, 1878—Graph. treatment of circular arch of constant section and fixed ends. (After Steiner's lectures).
Perrodil—Annales des ponts et chsussées, 1872 and 1876. (Only for symmetrical loading).
Winkler—Deutsche Bauzeitung, 1879 and 1880—Uber Lage der Stützlinie im Gewölbe."
Greene—Trusses and arches, anal. and discussed by graph. methods. Part III. Arches.

With respect to the principle of least resistance, which has been so extensively applied of late, the writer hopes at some future time to present some reflections. For the present he will only state that he considers the principle essentially a false one, and that applied to the determination of the true line of resistance in the arch, it gives fallacious results. The true line of resistance can only be found by the theory of elasticity. Having shown that the stability and strength of the arch depends on the position of that line, we proceed to state and demonstrate the following theorem due to Winkler:

"*For an arch of constant section that line of resistance is approximately the true one which lies nearest to the axis of the arch ring, as determinea by the method of least squares.*"

We say, *approximately*, it will be seen that the theorem is not true if that word

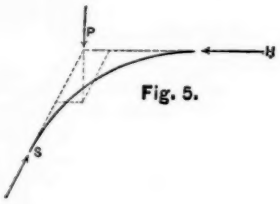


Fig. 5.

be left out. Further on, we shall try to show that the error is small, and does not invalidate the application of the theorem. The proof is as follows:

The *first supposition* is that *the loading is vertical.* We have elsewhere noticed that this supposition is not always true. The differential equation of the *equilibrium curve* (not the line of resistance) for giving loading is

$$\frac{d^2\mu}{dx^2}=\frac{q}{H} \quad . \quad . \quad . \quad (4)$$

when q=load per running foot at the point in question, H=Horizontal thrust of the arch, which is constant, μ and x =the condinates, horizontal and vertical.

For at any point S of the curve the resultant of the horizontal thrust H and the total load on the arch between the point in question and the point when the equilibrium curve is horizontal acts along the tangent at S, hence

$$\frac{d\mu}{dx}=\frac{P}{H} \text{ and } \frac{d^2\mu}{dx^2}=\frac{1}{H}\cdot\frac{dP}{dx}=\frac{q}{H}.$$

Integrating eq. (4) we find

$$\mu=A+Bx+\frac{f(x)}{H} \quad . \quad . \quad . \quad . \quad (5)$$

where A and B are constants, and $f(x)$ some function of x depending on the loading.

If y is the ordinate of the axis of the arch ring at S, referred to the same coordinate axis, then the vertical distance of the equilibrium curve below the axis of the arch ring will be

$$\mu-y=A+Bx+\frac{f(x)}{H}-y \quad . \quad . \quad . \quad (6)$$

The *second assumption* is that the line of resistance may be considered to coincide with the equilibrium curve. On this supposition eq. (6) gives the distance between the axis of the arch ring

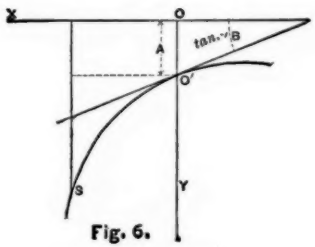


Fig. 6.

and the line of resistance. We shall consider these assumptions farther on.

Let us now examine the conditions necessary in order that the line of resistance may approach as near to the axis of the arch ring as possible, that is, the conditions under which the sum of the squares of the *vertical deviations* is a minimum. This sum $S=\Sigma(\mu-y)^2$ will be a minimum when $S_1=\int(\mu-y)^2\,ds$ is, that is, when the first differential coefficients of S_1 with respect to the arbitrary constants A, B, and H, are equal to zero. Now we have

$$\frac{dS_1}{dA}=\frac{2dA\int(\mu-y)ds}{dA} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$\frac{dS_1}{dB}=\frac{2dB\int(\mu-y)x ds}{dB} \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$\frac{dS_1}{dH}=\frac{-2H^{-2}dH\int(\mu-y)f(x)ds}{dH} \quad . \quad . \quad (9)$$

Hence the conditions for a minimum S_1 are

$$\int(\mu-y)ds=o \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$
$$\int x(\mu-y)ds=o \quad . \quad . \quad . \quad . \quad . \quad (11)$$
$$\int f(x)(\mu-y)ds=o \quad . \quad . \quad . \quad . \quad (12)$$

Since $f(x)=H(\mu-A-Bx)$ the last condition takes the form

$$\int\mu(\mu-y)ds-A\int(\mu-y)ds-$$
$$B\int x(\mu-y)ds=o \quad . \quad . \quad . \quad . \quad (13)$$

or, with regard to (10) and (11)

$$\int\mu(\mu-y)ds=o \quad . \quad . \quad . \quad . \quad . \quad (14)$$

Now we have, from the properties of the equilibrium curve, $\mu-y=\frac{M}{H}$, if M is the moment with respect to the axis, hence the above conditions may be written

$$\int Mds=o \quad . \quad . \quad . \quad . \quad . \quad (15)$$
$$\int Mxds=o \quad . \quad . \quad . \quad . \quad (16)$$
$$\int M\mu ds=o \quad . \quad . \quad . \quad . \quad (17)$$

Since $\mu=y+(\mu-y)$ the last equation may be written

$$\int My ds+\int M(\mu-y)ds=o, \text{ or}$$
$$\int(\mu-y)yds+\int(\mu-y)^2ds=o \quad . \quad . \quad (18)$$

and since $(\mu-y)^2$ is to be a minimum, the last tern will be small compared with the first, and may be neglected, so that the last condition becomes

$$\int(\mu-y)yds=o, \text{ or } \int Myds=o \quad . \quad . \quad (19)$$

The three equations (15) (16) and (19) are known to be the three equations which determine the position of the true equilibrium polygon for flat arches of constant section with fixed ends, as deduced by the theory of elasticity. Hence our theorem is demonstrated under our assumed conditions, which we shall now proceed to consider a little more in detail.

It must be admitted that this demonstration is not so rigid as could be desired, yet it is believed that upon examination it will be found more accurate than it at first sight appears. The first assumption upon which it rests was that the loads act vertically. If we assume inclined loads we meet with difficulty, because we cannot bring the equation of the equilibrium polygon into the form given by eq. (5). In that equation A is the ordinate at the origin, B the tangent of the angle with the x axis at the origin, and $f(x)$ the moment about S of the load between that point and the origin. Since those loads act vertically their moment is of course only a function of x, and would be the same were S anywhere on the ordinate on which it lies, that is, $f(x)$ does not depend on H at all. But if the forces acting on the arch between S and O′ are inclined, the moment of their horizontal components will depend on the ordinate of S, and hence on H, and the equation to the equilibrium polygon takes a form different from eq. (5).

The second assumption was that the equilibrium polygon can be taken to coincide with the line of resistance. This may in some cases involve considerable error, but by a few changes which do not affect the equations, the investigation may be to a great extent freed therefrom. To find the ordinate y of the equilibrium polygon for an abscissa x, we must compound the force acting at the crown, P, with the weight and load on ACFB. To find the center of pressure on the joint DE we compound P with the weight and load acting on ABEDC. The assumption that the line of resistance coincides with the equilibrium polygon involves, therefore, as regards the outer forces for each joint, an error equal to the weight of a prism of stone like DEF. This error will be zero for a vertical joint, and in general will be zero at the crown of the arch, and will attain its maximum value at the springing. Compared with the load really acting on DE, however, the weight of the prism of stone DEF will be in general very small, so that the error from this source will, as Scheffler has remarked, be very insignificant when compared with the error involved in the fact that to find a point in the equilibrium curve we find the intersection of a certain line with DF, while to find a point in the line of resistance we find the intersection of almost the same line with DE. The true line of resistance and the curve found by determining the intersection with each joint as DE of the resultant of P, and the corresponding load on ABFDC, will lie very near together, but the equilibrium curve may diverge considerably from these lines. This difficulty may be in great part

avoided by the following considerations: Let D′E′ be a joint at a very short distance from DE. Project S and S′ on the axis of x at G and G′, and lay off GN, G′N′, so that the area of the rectangle GGN′N equals, to some assumed scale, the load acting on the part of the arch DEE′D′. The writer is well aware of the difficulties attending the exact determination of the distribution of the loads through the spandril walls on the arch ring, but in absence of any exact knowledge it is best, as it is usual, to consider the loads to be carried directly downwards, so that if DC represented the intensity of the load acting directly above D, the force on DD′ would be represented by DD′CC′. If we perform the construction just indicated for all points of the axis we obtain a curve $N_0 N_1$ such that any area $AN_0N_2G_2$ represents the load acting between the crown and the joint through S_2, the point on the axis directly below G_2. The equilibrium curve for this load would be represented by eq. (5), and to find the point corresponding to the joint DE, for example, we should compound P with the true load between the crown and this joint, and find the point where the resultant intersects GS. The proof of Winkler's theorem is not changed, while we have entirely got rid of the error due to the prism DEF, and partly rid of the error due to taking an intersection with DF instead of with DE. It is believed that this new equilibrium curve may be taken to coincide with the line of resistance, especially in the case of the true line of resistance.

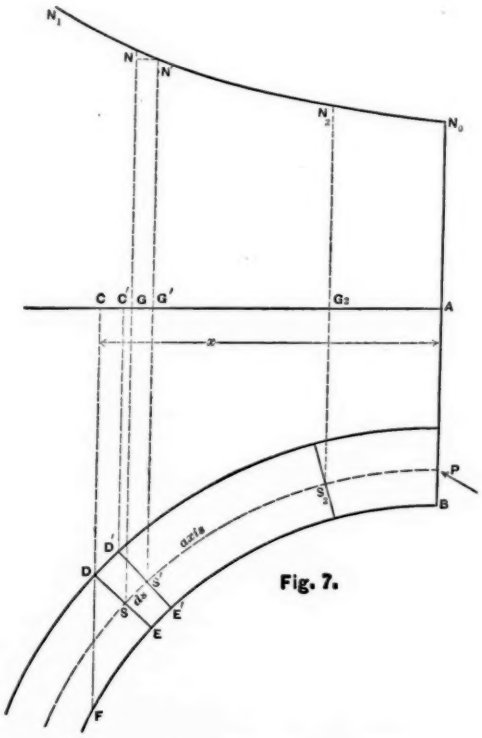


Fig. 7.

We have measured the deviations of the line of resistance from the axis vertically. It may be thought that they should be measured normally. To do so involves some difficulties, and it is reasonable to suppose that if the sum of

the squares of the vertical deviations is a minimum, the sum of the squares of the normal deviations will be a minimum too.

We have assumed that the conditions above found correspond to a minimum. There is no need to examine whether it does not represent a maximum, for a glance convinces us that the function in question has no analytical maximum.

The equations (15), (16) and (19) are only approximately the conditions determining the position of the equilibrum polygon, for arches of constant section. The exact conditions are the following, for any arch:

$$\int M_1 ds = o;\ \int M_1 y ds - \int P_1 dx = o;$$
$$\int M_1 x ds + \int P_1 dy = o,$$

the origin being at one of the abutments, and in which

$$M_1 = \frac{M}{EI} + \frac{M}{EFr^2} + \frac{P}{EFr};\quad P_1 = \frac{P}{EF} + \frac{M}{EFr}$$

I being the moment of inertia, and F the area of the section, r the radius of curvature, E the modulus of elasticity, M the moment and P the axial force. For circular arches of constant section these become *

$$\int M dx = o;\quad \int M dy = o;$$
$$\int \left(M + \frac{I}{Fr^2 + I} Pr \right) ds = o.$$

For flat arches r is large and P in almost all cases may be neglected, so that we easily find the approximate equations (15), (16), (19).

Assuming the truth of Winkler's theorem, in the case of arches subjected to forces slightly inclined and whose section is not exactly constant, we are enabled to state generally the theorem. *If any line of resistance can be constructed inside the arch ring, the true line of resistance lies within it also, hence the arch is stable.* For if any line of resistance can be so constructed, we can construct the maximum and minimum lines of resistance, and some intermediate line will be nearer to the axis than either of these two, as has been remarked above. It is true that it does not follow that because the maximum and minimum lines recede from the axis as far as possible at several points the sum of the squares of the deviations in each case is greater than in the case of any intermediate line, but in fact the lines of resistance are generally regular and continuous curves, so that it is believed that this will be the case in fact. We may also assert: *If any line of resistance can be drawn within the middle third of the arch ring, the true line of resistance can also be drawn within the same limits, hence no joint will tend to open.* It may perhaps be best, however, to take a margin of safety, to provide for the various contingencies which can affect the true line of resistance, and to increase the depth of the arch ring a little above the depth given by the above condition, as suggested by Prof. Cain.

And, finally, in order to be assured of the strength of the arch, it will be sufficient to proceed as follows: Draw a line of resistance for the given loading, making it pass through the centers of the joints at the crown and springing. This may be considered an average line, and will enable us to find, nearly enough, the force acting on each joint. Then calculate by mean of eq. 3 the smallest value of $S_1 D$, and laying it off at each joint from both extrados and intrados, we have two curves within which the true line of resistance must be made to lie, that is, between which we must be able to construct a line of resistance. These lines, however, will generally lie outside of the middle third of the arch ring.

For the investigation of the frictional stability of the arch, as well as for the details of the graphical construction of lines of resistance, we must refer to the books of Sheffler and Cain.

If the element of stability offered by the resistance of the spandrils be neglected, as in the above, it will be found in many cases that in order to confine the line of resistance within the inner third of the arch ring, particularly in the case of arches which are semi-circular, or nearly so, the thickness of the arch ring must be very great at the springing. In view of this fact, such arches are often built with the backing carried up, with squared vertical and horizontal joints, to the joint of rupture, or joint below which a thrust from without is necessary for the stability of a linear arch similar to the given one.

* See Allgem. Bauzeitung, 1878.

This joint will usually lie between the points when the inclination of the axis of the arch ring to the horizon is 45° and 60°. The part of the arch ring below the level of the top of the backing is considered as forming a part of the abutment, and only the part above that point is considered as forming the arch proper. There seems to be no objection to this treatment, although the cost of carefully carrying up the backing to points about 45° from the crown, may perhaps form quite an item, but it may be noticed that inasmuch as this method renders it unnecessary to investigate arches extending more than 60° each way from the crown, it forms an additional argument in favor of basing the theory of the stone arch on Winkler's theorem, which for such arches may be considered as practically accurate. For arches which are not flat the equations on which it is founded are, as noticed above, not exactly correct, and the flatter the arch, the more do they approach absolute accuracy.

In conclusion, a few historical notes regarding theorems somewhat similar to Winkler's may not be out of place. *

Hagen, in 1844 and 1862, said that the question was to determine the line of resistance which affords the greatest safety, though he does not assert this to be the true one. He finds that line of resistance for which the absolute pressure on the most compressed joint is a minimum, but his supposition regarding the distribution of stress along a joint is incorrect. It may be remarked here that the supposition we have made will be also incorrect if the arch ring is composed of several concentric rings having no bond with each other. Such a construction is not advisable, because each ring will act for itself, and it cannot be determined how the load is distributed among the several rings.

Hänel, in 1868, determined the position of the *most favorable* line of resistance, as he called it, according to the same principle, but based on the correct distribution of pressure on a joint. He also does not assert that this will be the true line of resistance. This assertion, however, was made by Drouets in 1865, who called the principle a metaphysical one, and said that the molecular resistances would so adjust themselves that the greatest absolute pressure in the arch would be a minimum.

That the principle is a metaphysical one, few will deny, but its incorrectness is shown by the fact, noticed by Dupuit, that it leads to the supposition that the reactions of the supports of a continuous girder must be all equal. Durand Claye gave in 1867 a graphical treatment according to Drouet's principle.

Culmann, in 1866, asserts exactly the same principle. He was followed in 1875 by Du Bois in this country. He says that of all possible lines of resistance the true one is the one which lies nearest to the axis, so that the pressure at the most compressed edge is a minimum. His proof is, if the material is so weak and the arch ring so thin that only one line of resistance is possible, which does not cause a rotation or a crushing of the material, then this is the true one. If now the material gradually hardens, no change can take place, hence this line of resistance must be the true one for any material. This assumes the theorem that if only one line of resistance is possible, it is the true one, which has not been proved. In fact, the principle that the true line of resistance is the one involving the smallest maximum stress supposes, as it were, a certain power of thought in the material, together with an endeavor to exert only as much force as is absolutely necessary. However reasonable this may seem by its analogy with cases in which power of thought is present, it has not been proved. The principle has been humorously called "the principle of the foxiness of the material." (Das Princip der Schlauheit des Materials.)

The principle that if any line of resistance is possible in the middle third of the arch ring, the true one lies in the middle third, and hence no joint will have a tendency to open, was stated by Harlacher in 1870. This assertion is disputed by Winkler, in 1879, who says it is not in general correct. It seems to the writer, however, to follow directly from Winkler's theorem.

Cain, in 1879, says that it "seems

* For historical notes on the theory of the stone arch, the reader is referred to Scheffler, pp. 208-232, and to two articles by Winkler, Deutsche Bauzeitung, 1879 and 1880. "Uber Lage der Stutzlinie im Gewölbe." From the latter most of the above notes have been taken.

highly probable that the actual line of pressures is confined within such limiting curves, approximately equi-distant from the center line of the arch ring, that only one curve of pressures can be drawn therein, corresponding, therefore, to the maximum and minimum of the thrust in the limits taken." This he does not prove, however, but it agrees, in a general way, with our conclusions.

To sum up, then, it would seem that the theory of the stone arch is comprehended in the following theorems:

1°. The stability and strength depends upon the true position of the line of resistance, which can only be found by the theory of elasticity.

2°. On account of the various contingencies which may in practice disturb the position of the line of resistance, its exact determination is impossible.

3°. The principle of the theory of elasticity show, however, that the true line of resistance is the one lying nearest to the axis of the arch ring.

4°. Hence it is not necessary to apply the principles of that theory in detail, inasmuch as if any line of resistance can be drawn within the middle third, and at the same time within the limiting lines for crushing, then the arch will possess sufficient stability and strength..

THE INSTITUTION OF MECHANICAL ENGINEERS.

From "The Engineer."

INAUGURAL ADDRESS OF THE PRESIDENT, MR. E. A. COWPER.

I do not propose on the present occasion to trouble you with any long history of the progress of mechanical engineering, as various matters press themselves very urgently on our notice at the present time, and demand, it appears to me, very serious reflection on our part. I allude of course, firstly to the very great and general depression in trade that has now held its dull course for years; and, secondly, to the means in our power that are, or are not, being taken advantage of to promote the manufactures and commerce of the country. Now, I am not one of those who would, for a single moment, think of sitting quietly with one's hands before me, and saying, 'If foreigners choose to do the work which we have been in the habit of doing exclusively for many years, and thus take away our trade, we cannot help it, as we cannot prevent them from becoming better educated in manufacturing arts than they were.' But let us examine the situation frankly and fully, and see the reasons of the changes that have undoubtedly taken place; and we shall find that one of the primary causes consists in the fact—which I ventured to allude to on a previous occasion—that during the thirty years' war on the Continent, very little attention, comparatively speaking, was given to manufacture, because the populations were much engaged in preparing for fighting, and in actual warfare, and in tilling the ground for a bare subsistence. But before considering the present era, let us glance—and glance only—at the fact, that in by-gone times it was much the fashion, if some ingenious engineer were required for a special work, such, for instance, as making a dock, or a bridge, draining fens, or other public works, to call in a Dutchman, or an Italian, or other foreigner, so that we must not say that in those days England always produced just the men that were wanted. I think it is advantageous and wholesome for us sometimes to look around, and to examine and reflect on what has made this country the manufacturing and successful country that it is, and what is now wanting to enable us to continue to hold that proud position securely. I am well aware that some thinking men consider that technical education, such as is given in Germany, is what is wanting in this country, and, although I think much more than this is needful, I give all honor to the earnest men who are striving to promote technical education in London, and in all the large cities and towns of England. But I most emphatically call

the attention of manufacturers generally throughout the country—not to mechanical engineers only—to the advantages that they would reap, if they generally and sysematically threw more enterprise into their business, and showed greater interest in investigating and adopting new improvements in manufactures. I will attempt to illustrate my meaning, and to cite a few examples of real enterprise, and the immense effects they have had on the manufacture, the commerce, and the very position of this country amongst nations. Take for instance the new manufacture which has made this important town, and is its chief industry—and is, in fact, the cause of our being assembled here to-day. I allude, of course, to the Bessemer manufacture; and one reason why I call it 'the Bessemer manufacture' is, that we owe not only the invention to its author, but also the introduction of the steel when made into the market. For it is well known that manufacturers had not the enterprise to take up the invention and prosecute it to a perfect success, until Sir Henry, then Mr. Bessemer, and certain capitalists had spirit enough to go into the business; when, with the further assistance of Mr. Mushet's manganese, it was soon an accomplished fact, that good steel could be made in immense quantities at a cost altogether unheard of before. Here we see gentlemen altogether outside the trade, giving the country an essentially good thing, and providing work for thousands of our artisans. The introduction of the Siemens process for very mild steel also deserves especial notice, and the steel is in great demand. I believe it is to such efforts as these, and to such enterprise as we shall see developed here at the steel works, the shipbuilding works, the docks, the jute works,&c., that we may look for the retaining and increasing of our trade and commerce. I wish to allude to a few other inventions and enterprises, which every thinking man must admit have had a like effect on manufactures and commerce; and I must at the same time, and in common justice, mention other cases in which the British manufacturer has, I am sorry to say, been lamentably behind in the race of improvement. I have in my lifetime seen the whole of the railways in the kingdom under construction, with the exception of the Stockton and Darlington, and the Liverpool and Manchester; and the latter I went down to see the first year after its construction, so that I have taken note of a very large number of what are commonly called 'modern improvements;' and I may, perhaps, also name a few of those that were young when I was a lad. There is no doubt but that we are largely indebted to our rich natural resources in mineral wealth, such as coal, clay, lime, salt, stone, iron, lead, copper, tin, &c., whilst another very important factor is the natural wit and industry of the English character, which is so different in many respects from the lethargic, volatile, or idle character of some other nations; and I argue that, in view of these facts, it would, indeed, have been a shame, if many good, new, and useful results had not been produced, though I maintain that many more might have been generated, had more enterprise and less conservatism in old ways been shown.

One of the earliest and most marked improvements, in the conveyance of merchandise of all kinds inland, was the large development of canals by Brindley, at once reducing the cost per mile from about 10d. to 1d.; so that the materials produced in one part of the country were able to be transferred to other parts, where it was possible to utilize them; and merchandise could also be conveyed to large towns or ports for shipment. This improvement tended largely to develop the resources of the country, and greatly to assist those who were principally dependent upon agriculture. The successful exertions of Smeaton in improving water wheels and windmills did much to supply the country with power for grinding and pumping, as well as for forge and tilt hammers, and for blowing engines in ironworks; but the amount of water power available in the country is comparatively small, far too small too meet the necessities of manufactures. The next vast step in improvement was undoubtedly the introduction of the steam engine, first by Newcomen, simply for pumping, and secondly by Watt for general purposes, thereby immensely stimulating the old manufactures of the country, and giving rise to many new ones. The

case of Watt is one which clearly shows the advantage of the patent laws in stimulating invention, by enabling the inventor to reap a portion of the advantage of his own discovery; for it was distinctly the fact of his having a patent that caused his money partner, Boulton, to persevere in bringing the invention to bear on an extensive scale. And here, in passing, I may call attention to the fact that fourteen years was not enough to develop the most useful invention of our times, and that another fourteen years was given. The service rendered also by Trevithick, in the introduction of the high pressure steam engine, was much more important than is generally acknowledged; it certainly is not universally known that he ran a locomotive engine on a circular railway about 1804, in Euston square. I may mention that my own father saw it running there, inside an inclosure, and it ran round so fast as eventually to leave the rails. The progress of improvement in manufactures after the invention of Watt was brought to bear was much more rapid. Cotton spinning was quickly improved; Arkwright introduced his spinning frame; Crompton introduced his mule, and Roberts his self-acting mule; and finally, Cartwright introduced the power-loom. The manufacture of soda from common salt was introduced, and was a most valuable invention. The paper-making machine was invented: bleaching and dyeing were much improved. The printing machine was brought to bear, and at once spread knowledge at the rate of 1,200 large sheets per hour, printed on both sides, in place of small sheets, only printed on one side, at 250 per hour. I trust you will excuse my mentioning this in honor of my late good father. A little later the Jacquard or figuring loom was brought forward; steam navigation, and later on, ocean steamers, were a complete success; and pottery and porcelain were much improved in various ways. Then came the grand strides made by railways, and the consequent cheap and quick conveyance of passengers and materials in all directions, thus enabling numbers of industries to be established and worked with advantage, and giving employment to tens of thousands. In shipping, it only required experience of the entire success of the first iron ships, the Garry Owen, and Aaron Manby, to give iron ships a firm footing, though the advocates of wooden ships delayed their introduction for a time. At the present time, the immense advantages obtained by the introduction of mild steel in shipbuilding are increasing the shipbuilding trade of this country in a remarkable degree. The great economy with which steamships can now fetch and carry minerals of low value, in enormous quantities, throughout the world, combined with the immense facilities afforded by railways, enables almost any kind of material to be transferred from any one spot on the globe, where it may be produced, to any other point where it may most economically be utilized, and where real improvements in manufactures may be made. As an example, some of the most sulphurous copper ores of South America, formerly not worth transport, are now used in immense quantities, owing to the invention of the Gestenhofer furnace, in which the burning of the sulpher from the powdered ore accomplishes its calcination. The sulphurous vapor thus produced is used to make sulphuric acid, and the acid employed to make soda out of common salt. I merely mention this as one instance among hundreds in which several different manufactures have been improved at the same time by one simple invention. Telegraphs then came to our aid, to facilitate the interchange of information, and particularly did ocean telegraphs help greatly in the more important communications between continents. I must not here dwell upon the immense variety of telegraph instruments and appliances; but the great acceleration accomplished by duplex and quadruplex signalling, through one wire in both directions, has been a marked improvement of our age, and contrasts strongly with Professor Wheatstone's original four wires, with the rails of the railway, as was supposed, for a return wire. Passing on to the most recent improvements, we shall see, for the first time in England, liquid steel, in ingot moulds, submitted to the pressure of high pressure steam, in order to compress the bubbles of carbonic oxide, or carbonic acid gas, in the mass, and so render the ingot more sound; on the same principal as is

employed by Sir Joseph Whitworth when he uses hydraulic pressure. Another very interesting manufacture which we shall have full opportunity of seeing, is the jute manufacture, which has risen to such large proportions, that some manufacturers have moved their establishments to India, where the jute is grown, and where labor is very cheap; whilst the recent use of the stump, or lower part of the jute stalk, for paper making, has gone some way to reduce cost. Wire rolling mills are also to be seen in the neighborhood, where lengths of a quarter or even half a mile can be rolled out from one billet ready for being drawn. There is, likewise, a Hoffman kiln for burning bricks in the most economical manner, by utilizing the heat of bricks that have been burnt for heating up bricks to be burnt. The large docks, with immense concrete retaining walls, and their large gates and other appliances, will be found well worthy of attention; and Joy's new slide motion will demand careful consideration, particularly in reference to its application to locomotives, an excellent specimen of which has been brought here by Mr. Webb, with the motion applied in his own way, and with the last improvement in a slide valve, which gives a double quick opening at the beginning of the admission. I must not dwell on other improvements in machines and manufactures which have certainly helped the commerce of this country, such as the preservation of food, stereotype printing, preparation of india rubber, fog signals, gas manufacture, photography, weaving, plating, metals, machine tools, candle making, lace making, tea rolling, machinery for lifting weights, hydraulic machinery, interlocking railway signals and points, railway brakes, writing instruments, sugar machinery, both cane and beet, bolts and nuts, screws, locks, anchors, steam hammers, lead and iron pipes, blast furnaces, gun cotton, dynamite, nitro-glycerine, steel masts and yards, steering apparatus, economical engines, microscopes, telescopes, spectroscopes, thermometers, for discovering icebergs at sea, artificial leather, agricultural implements, sinking piles by means of a jet of water, fire engines, &c.; and I may, perhaps, add to these Sir Henry Bessemer's high temperature furnace, with gases under pressure, and Dr. Siemens' elegant experiment of melting steel in a crucible with the electric current, and his plan of stimulating the growth of plants. Perhaps you will be inclined to ask me why I have thus conjured up to your mind's eye a number of inventions and improvements which you know have helped to make England's greatness; for this reason, that I want manufacturers to appreciate much more than they do at present, that such vast improvements having been made, further important steps can be taken, so as to keep England always in advance of all other nations in manufactures and the arts, if only more enterprise and energy are shown in taking up known good things, inventing new processes, and prosecuting them to success. For instance, sewing machines ought to be made here, and I urged English makers years since, to go in thoroughly for making every part accurately and by machinery, so as to fit together at once without "fitting," but I could not get this carried out, and now sewing machines come from America literally by millions, though labor is dearer, metal is dearer, and there are upwards of 3,000 miles of carriage against them. But "machine manufacture" is cheaper and better than "hand making." In gun making I counseled some of the Birmingham makers, years before they did anything in the matter, that they would actually lose their trade if they did not adopt good machinery to manufacture every part exact to size; and, at last, when the Government had the means of doing most of the work, they did adopt machinery, but many years too late. Then, with regard to common pumps, they are now imported from America by thousands, and are sold here without being commonly known to be American; clocks and watches also come in immense numbers, some of them very cheap and common, whilst others are very well made. Another trade, nearer, perhaps, to most of us, is that of rolled iron girders, which, I am sorry to say, are coming by hundreds and thousands from Belgium; indeed, almost every house, that is now built in London with rolled iron girders, is supplied from Belgium. These things should not be; we have iron in plenty, and labor in abundance, but we

want special machines, schemed as fast as they are wanted, to fit the work properly, and turn it out accurately in large quantities; and we should show more enterprise in adopting a good "new thing," which I am sorry to say is what some of our old-fashioned manufacturers are slow to do, often little knowing how they damage the trade they are in by not adopting the best known process. Finally, I venture to think that one of the best results of our Institution meeting in various localities, from time to time, as we do to-day, is, that there is free intercourse between those who are in one line of engineering and those who are in another line; and that such comparing of notes and observations as naturally takes place in conversation is most conducive to the obliteration of prejudices and wrong notions, and particularly to the removal of the illusion, that what is now being done cannot be improved.

THE MANUFACTURE OF ALUMINIUM, SODIUM AND SIMILAR METALS.—A patent has been obtained by Mr. W. P. Thompson, of Tranmere, for a novel process of manufacture of aluminium, sodium and similar metals, which, if successful, would very greatly reduce the present high price of these metals. Liquid iron, either alone or in conjunction with hydrogen or carbon, is to be the reducing agent, and the operation is to be conducted in an apparatus similar to the well-known Bessemer converter. This apparatus is made up of two characters. After the iron has been fused in the one it is transferred into the second by turning the converter. Through a tube opening into this second chamber, hydrogen, or carburetted hydrogen, is allowed to enter, and through another one chloride or fluoride of aluminium in a state of fusion or as gas. Hydrogen and ferric chloride escape, and in the converter remains iron alloyed with aluminium and carbon. This mixture is again transferred to No. 1 chamber, where the carbon is to be burnt by a current of air. After transferring to No. 2 the process of reduction is to be continued until the iron is almost wholly consumed, when hydrogen alone is to be used as reducing agent. Thus an iron-aluminium alloy results. For the preparation of sodium hydrogen is not requisite. Iron, mixed with much carbon, is to be heated with caustic soda in the converter, and the sodium, said to be formed under these circumstances, is simply distilled off. When all the carbon is consumed the iron may be worked into Bessemer steel, or may be again recarbonized. Iron and potassium not forming an alloy the method is not well applicable for the preparation of potassium. For the manufacture of pure aluminium, sodium is to be preferred in the manner described, and then in the chamber containing the metal, chloride or fluoride of aluminium is to be allowed to enter, air being excluded. The chamber is provided with stirring gear, and is lined with alumina, or a mixture of lime, magnesia and alumina. The inventor will likewise apply his process to the preparation of magnesium, calcium, strontium and barium. (Patent 2101, March 27, 1879.)

FRENCH FIRE-DAMP COMMISSION.—A few months after Leverrier's death a commission was established for determining the best means of protecting colleries from fire-damp. The commission has written a very long report recording the causes of 420 accidents. Sixty-four projects presented by private individuals have been examined, and some new instruments have been designed and are being constructed, viz., an anemometer by Vicaire, a manometer by Le Chatellier, and a registered apparatus for the quantity of air introduced into the galleries. But the composition of coal explosive dust has not been determined, nor the extent of its influence upon catastrophes; while the chemical analysis of fire-damp has not been completed. The only substantial benefit is a compilation of mining regulations and a series of propositions which have been transmitted to the French Ministry, and will be laid before Parliament next session.

"ABYSSINIAN" TUBE WELLS.

By ROBERT SUTCLIFF.

From the "Journal of the Society of Arts."

THE process of obtaining water by digging wells is of great antiquity, and that of boring scarcely less ancient. The particular method of obtaining water that it is the object of this paper to explain, is entirely modern. The crude idea of driving a tube into the ground for water is scarcely more than a dozen years old, and many of the appliances for driving tube wells are still more recent. In ancient days, wells were national property, and battles of possession have been fought over them. Now, a well can be made in many places in a few minutes, and the very deserts may be tapped, and clear springs obtained from them. Like many other clever inventions, the tube well owes its first existence to America, although it has been jocularly claimed as having been really originated by the negroes, who drove pointed bamboo canes into the earth, and slaked their thirst by drawing up the water through the pores of the cane. Be this as it may, the first iron tube well could only be driven in the very softest soils, and the tubes were struck on the head, which caused bending, injury to the screw threads, and fracture of the pipes. The pipes at first employed were also of inferior quality, such as are used for gas purposes, and were quite unsuited to the rough treatment and vibration that a tube well is subjected to. Upon the introduction of the patent into this country, the necessity for an improved method of driving the tubes became at once evident to those having charge of the invention.

This process it may be of interest to describe. In the first place, the materials used must be of the very best quality, and specially tough and good iron is required for the tubes. The first tube is pointed and perforated up for a few inches, with holes varying from one-eighth to quarter inch. The point is somewhat bulbous, but only sufficiently so to make clearance for the sockets by which the tubes are connected together. On the tube a clamp is fastened, provided with steel teeth, so as to grip the tube. This clamp is tightened by means of two bolts. Next, a cast-iron driving weight, or monkey, is slipped on to the tube above the clamp. The tube, thus furnished, is stood up perfectly vertical, in the center of the tripod; ropes are made fast to the monkey, and driving is commenced by two men pulling the ropes, and allowing the monkey to fall on the clamp. It is particularly important that the bolts of the clamp are kept tight, so that no slipping takes place. When the pointed tube has so far penetrated the earth that the clamp reaches the ground, the bolts are slackened, and the clamp raised again some two or three feet. Length after length of the tube is thus driven into the earth, being connected together by socket joints. It will be noticed that the tube well proper is, therefore, self-boring, and that no core of earth is removed.

One of the first questions that will suggest itself to a thinking mind is, will not those small perforations be blocked entirely up by being thus forcibly driven through the earth. This was the American's first idea, and he provided a sort of sleeve, in the shape of a sliding tube over the perforations, to protect them from the earth. Experience, however, has proved this protection to be quite unnecessary. The perforations are made about four times as numerous as is necessary for obtaining a full flow of water from the tubes. Earth does find its way into the tube-well in pellets, like the casts from a worm; but some of the perforations are always left sufficiently open to allow water to pass into the well, and if the soil comes rapidly into the tubes, it is easily mixed with water poured down from the surface, and drawn up by ½-inch tubes, to which a pump is attached. To thoroughly clean and open the perforations, an ingenious contrivance has, however, been utilized. Long before the tube wells were invented, a pump was manufactured that, by lifting the handle, would allow the water to run out of the tail-piece, and thus prevent freezing in

winter. This sudden liberating of a column of water that is maintained above its normal level, is the method which is employed to clear out the perforations of a tube well. In skillful hands, the water can be kept in a state of agitation, being alternately allowed to press through the perforations, from the inside and from the outside; and before the whole column of water has descended to the level of the spring, it is caught up by the pump, and a fresh supply drawn into the tube. In this way the perforations are syringed, as it were, free from all soft obstructions, and the excess of holes over what is required, makes the closing of a few by grit which is too large to pass through, of no consequence. This action of the pump is not only useful in clearing the perforations, but in some soils it plays a most important part in the development of a supply. When all the holes are free, the fall of the column causes jets of water to disintegrate the earth, and by this means the finer and softer particles are pumped to the surface, and either an actual cavity is formed below, or, in gravel, a sort of filter bed is left, out of which all the sand within reach of the pump has been withdrawn. It should be stated, that the first presence of water in a tube well is ascertained by an ordinary plumb-line, which is also useful for gauging the quantity of earth in the tubes. Having got the tube well into the spring from which it is to draw the perforations all free, and the earth thoroughly disintegrated in the immediate neighborhood of the point, it remains to describe the method of pumping.

Until this plan of obtaining water was discovered, all pumping was done by means of a suction-pipe communicating with the well or bore-hole. As the atmosphere had free access to water in the well, the action of the pumps was simply to draw water out of the reservoir, and there its duty ended. The method of pumping a tube well is entirely different; all atmospheric pressure on the water in the tubes is removed at each stroke of the pump, and hence the supply is drawn to the spot, instead of simply flowing there by gravitation. Although the tube wells achieve this result as it were by accident, the importance of the fact is now generally acknowledged by engineers. Many engineers were of opinion that it would be impossible to obtain water at all, if the atmospheric pressure were excluded from the well, but they did not pursue their reasoning quite far enough. It is true there must be atmospheric pressure somewhere on the water that we pump from, but it need not be in the immediate vicinity of the well. Perhaps it is miles away. Pumping in this way, we have not the tiny reservoir of an artificial well, but in some cases natural underground lakes, one might almost say, seas of water, to draw from. Some here may recall how our army, during the Abyssinian war, was supplied with water by these tubes, and it was the prominence which that war gave to the invention that led to the present prefix to their name. For campaigning purposes the wells were only used singly, as one or two were found sufficient to supply the wants of a number of troops. When, however, large supplies for manufactories, towns and villages were needed, a fresh development in the system took place. Instead of single wells of great diameter, groups of moderate size were driven and coupled together by horizontal mains, so that powerful steam pumps could draw from many wells at the same time. The great friction that would be caused by drawing an enormous body of water to a single spot is thus avoided. Wells so coupled draw from a very large area of ground, and the water-level at any one spot is not so rapidly lowered. The very action of the pump, too, in drawing the water to the wells, opens and maintains channels of communication which help to keep up the level of the water. In putting down plant for a large supply of water, a trench, hundreds of feet in length, and some two or three feet in depth, is dug, and tubes are driven every twenty feet, and coupled by mains as already described.

It may be interesting to refer to some particular instances, where large supplies of water are thus obtained. At West Thurrock, in Essex, a cement company is pumping from two 5-inch tube wells, about 80 feet deep, 220,000 gallons per day of 10 hours. Another cement works at Northfleet is pumping 60,000 gallons per day. These have been pumped daily for about four years, and still give a

constant supply. As expense is an important feature, it may be mentioned that the cost of these did not exceed £60 each. The coupled tube wells are to be found in greatest numbers at the centers of beer manufacture, where abundance of pure and cool water is an absolute necessity. At Burton-on-Trent, about two million gallons are pumped daily from these wells.

A feature of particular interest to this Congress is the question of purity of water supply. Tube wells very soon attracted the attention of sanitarians, from the fact that, being forcibly driven into the earth, there is little or no possibility of their being contaminated by surface drainage. Too frequently a dug well, from defective steining or other causes, becomes little better than a cesspool. It is also often expensive work to dig through water which is impure, in search of pure springs below, and still more costly, when the good water is found, to keep the bad from mixing with it. Accidental and temporary contaminations are not infrequent in dug wells. One of recent date came to the author's knowledge, which was of so serious a nature, as to cause a Government inquiry. It was found that in a certain district, supplied by a water company, enteric fever was raging with great virulence. No less than 352 cases occurred in places supplied with this particular company's water. In a very exhaustive report to the Local Government Board, it was clearly proved that a contamination of the wells, caused in a peculiarly offensive and direct way, was the origin of the epidemic. The instances of tube wells having been driven through contaminated water, and tapping pure springs below, are very numerous. A few may be mentioned, where the results are not merely one of opinion, but are proved by analysis. At Gravesend, within a stone's throw of the Thames, a 2-inch tube was driven through contaminated water, and reached a spring at about 50 feet, from which a sample was taken, and submitted for analysis. The analyst, after enumerating the particular constituents of the water, pronounced it to be the purest he had ever analyzed, with the exception of Loch Katrine. Bear in mind that this was taken from a well situated in the last place one would expect to find pure water, namely, within a few yards of the River Thames, which at that point is quite salt, and charged with London sewage. A point has sometimes been raised, as to whether water obtained from such positions is likely to remain pure when regularly drawn from, and, perhaps, severely taxed. This particular well has been made between four and five years, and subsequent analyses have proved the maintenance of its good qualities. It is used for purposes which necessitate a very strict watch over its excellence. The ships at that port fill their store tanks from this well, the Royal yacht among the number, the quality of the water is not therefore taken for granted.

At Deal, another illustration of the perfect isolation of a spring was afforded. Most of the wells in that neighborhood are brackish, and a supply of fresh water was needed for a flour mill, and for domestic purposes. Within the first 25 feet water was found in gravel, but too salt for use. The miller was under the impression that if the tubes were driven deep, fresh water would be obtained, and he discouraged any further testing of the water on account of the delays in so doing, until 100 feet had been driven. At 117 feet the pump was again applied, but instead of being better, the water was as salt as brine. The engineer having charge of the work noticed that at the depth of 45 feet the water level differed both from that at 25 and that at 117 feet, and the fact suggested to his mind the desirability of testing the quality of this middle spring. A second tube was therefore driven to 45 feet, and from it quite fresh water was obtained. This happened five years ago, and the water still remains free from brackishness.

Hundreds of other instances might be mentioned, but these are so marked as to be sufficient for the purpose of illustration.

Some waters of good quality, but containing sulphate of lime, &c., are much injured by the exposure they get in ordinary wells, and the author has heard of dug wells at Burton-on-Trent that emit an unpleasant effluvia, and get unfit for use if not constantly pumped. This appears, therefore, an additional reason

for keeping the atmosphere from the spring.

When rock, solid stone, or incompressible clay is met with, a tube cannot be driven through it without first making a hole, and removing the cores. In some cases, however, there may be many feet of loose earth which can be easily driven through; this (especially if gravel has to be passed through) is a tedious process. The tubes, therefore, may be fitted with a temporary hard wooden point, which will allow them to be driven through the soft earth, and when an obstruction that cannot be penetrated is met, the point is knocked out, and, being wood and in sections, it floats to the surface of the water, and leaves an open-ended tube, through which ordinary boring tools can be passed to chisel and break up the rock. A tube can frequently be driven through gravel and clay to a depth of, say, 70 feet in a single day. To bore to the same depth in similar stratum frequently takes ten days or a fortnight. The saving that may be effected by driving through the loose stratum can, therefore, be readily appreciated, and, what is still more important, the upper part of the tubes are fixed more tightly in the ground than if a boring had been made to receive them. In some cases, however, hard strata come right to the surface, and the boring operation, consequently, cannot be deferred. When this is the case, instead of using a pointed tube, an open-ended steel shod pipe is driven into the hole as the boring proceeds. As the tools pass down inside the pipe they do not cut so large a hole as the outside circumference, and some little trimming down of the sides is left for the steel shoe to perform.

In great depths the single tier of pipes, with which the work is commenced, cannot be forced the whole way. Tubes, therefore, of smaller diameter are inserted; but, as to pump by the tube well method, air-tight joints are absolutely necessary, the final tube is continuous from the deep spring to the surface. In this way, tube wells 300 and 400 feet in length are put down, and if the spring, when tapped, rises to the surface, or within, say, 25 feet of it, only an ordinary lift-pump is required to obtain the supply. Where the water does not rise to the required height, a deep well pump can be lowered into the tube well, and worked by rods from the surface.

Bored tube wells are frequently put down in sets, and connected by horizontal mains, where large supplies are required.

The new water-works at the town of Skegness, in Lincolnshire, will be supplied by two bored tube wells thus coupled together. These wells are already completed, and a supply of pure water from the sandstone has been obtained, although salt water was passd through during the upper portion of the work.

In describing the method of driving tube wells in the commencement of this paper, mention has not been made of the latest system, which is more particularly applicable to tubes of large size. It is so simple as to merit a brief notice. An elongated cylindrical weight passes down inside the tube, and the blow, instead of being struck at the surface, is delivered where it is wanted, near the point which penetrates the earth. As water in the tube would impede the force of the blow, the first socket above the peforations is made sufficiently long to admit of a stout iron ring or washer being placed in the center of it, in such a way that the two lengths of tube, when screwed tightly together, butt against it, one on the under and the other on the upper surface. The interior of this ring is of sufficient size to allow the water to pass freely through it, but it has a screw thread cut throughout its whole length. During the operation of driving, the opening in this ring is closed by a steel plug, which is screwed down into it until its shoulder butts on the ring. The upper surface of the plug forms an anvil, on which the driving weight falls. The plug is readily removed and brought to the surface when the required depth has been reached.

The object of this paper has been to describe a particular method of obtaining water in large quantities, and free from contamination; but in the great question that this Congress is considering of National Water Supply, no one system can, under all the varying circumstances, be applicable. One town may have abundance of good water at its

feet, others may have to seek it and conduct it from a distance.

The collection of full information on this part of the subject is of the greatest interest and importance, and before a really national scheme of water supply is entered upon, it seems advisable that a complete hydrogeological survey of the whole country should be carried out.

Mr. Joseph Lucas has, for some time past, devoted special attention to this branch of geology, and has, single-handed, mapped out certain districts, and compiled much information into a compact and useful form. To carry out such a gigantic inquiry in a reasonable time, however, requires more assistance than a private individual can generally command, and, probably, it is in this direction that Government aid might, in the first instance, be most advantageously directed.

STEEL AND IRON FROM PHOSPHORIC PIG.

By C. B. HOLLAND AND A. COOPER, Sheffield.

From "Engineering."

ON THE MANUFACTURE OF BESSEMER STEEL AND INGOT IRON FROM PHOSPHORIC PIG.

BEFORE entering upon the subject of our paper, it might not be out of place to consider, for a moment, what is steel, and what is ingot iron. Steel has been defined as "an alloy of iron and carbon which is capable of being cast whilst in a fluid state into a malleable ingot," and all other elements usually found in the steel of commerce, such as silicon, sulphur, and phosphorus, may be regarded as impurities, and are more or less hurtful. In like manner, ingot iron may be defined as an iron which is capable of being cast whilst in a fluid state into a malleable ingot, and other elements found in it (including carbon) may in this case also be regarded as impurities. It follows, then, that those steels and ingot irons are the best and purest which contain the noxious elements in the least quantities, no matter whether they be produced from the finest brands of Swedish and hematite, or from common iron containing from $1\frac{1}{4}$ to 2 per cent. of phosphorus. And we think all will agree, if it can be shown that steel and ingot iron can be produced from the latter kind of pig of the same chemical composition, and capable of standing the same mechanical tests as that produced from the purer irons, that one is as good as the other for all purposes. It is not our intention to occupy the time of the Institute by referring to any of the numerous papers that have been written and the theories that have been propounded, during the last eighteen months, on the dephosphorization of iron by the Thomas and Gilchrist process, interesting and instructive as many of them are. It will be sufficient to say that, notwithstanding the great strides that had been made in the development of the process at the works of Messrs. Bolckow, Vaughan & Co., under the able direction of Mr. Richards (who must always be regarded as one of its earliest pioneers) and the very satisfactory results obtained by that company in the manufacture of steel from Cleveland pig iron up to the early part of November last, before we had seen the process in operation, there appeared to us certain difficulties which we feared would greatly retard its successful working from a commercial point of view. The first of these may be regarded as a technical one, and had reference to that part of the operation now well known as the "after-blow." Assuming, as we did, all the metalloids, with the exception of phosphorus and sulphur, to be oxidized before the commencement of this period, it seemed doubtful to us whether it would be practicable (having no definite point at which we could safely stop blowing corresponding to the drop of the carbon flame in the ordinary process) to burn out the whole of the phosphorus regularly, without sometimes carrying the operation too far, and thereby oxygenating the charge. And this, as all steel-makers will agree, is very apt to give trouble. Again, we had our misgivings about the gathering at the nose, concerning which we had heard so much,

and the delays which we thought must necessarily result from the indispensable and repeated turning down of the converter for sampling. It was at this time (early in November, last year) that we were invited to see the process, at the Hörde Works in Westphalia, and, through the courtesy of Mr. Pink, the manager of the steel works, our representative was not only shown the process in operation, but every information respecting the difficulties that had been experienced up to that time, and the means which had been employed to overcome them, was very kindly given to him by that gentleman. From the working at Hörde, it was apparent that the phosphorus was eliminated with regularity—there were no violent reactions on the addition of the spiegel, showing that the metal was not oxygenated to any great extent, and the steel made was of a mild quality, and very malleable. On November 20th, we commenced to work the process in Sheffield, using a mixture of white Lincolnshire and No. 4 forge irons. By sampling during the after-blow, we were enabled not only to remove the phosphorus in a very satisfactory manner, but also to make good and malleable steel; but the gathering of the slag and metal at the nose of the converter at first proved such an obstacle to rapid working, that although we employed men with long bars to fettle after each operation, at the end of from 12 to 18 blows, we were compelled to stop, allow the converter to cool down, and cut out the accumulation. At this early stage we were of opinion that by increasing the area of the nose, we should get a decreased pressure of gases, and consequently the slag and metal would not be carried up so high, and that this would remedy the evil. Our experiment proved to us conclusively the fallacy of this, for after altering the shape of our converter so that the area at the mouth was doubled, and lining up with basic bricks as before, although we worked under precisely the same conditions, this converter was completely slagged up at the nose, and was unfit for further work after ten blows, simultaneously with the other converter and with the mouth of usual size, lined with basic bricks. We tried admitting blast at the throat, with the view of burning the carbonic oxide, and so increasing the temperature at this point, but the results were not sufficiently encouraging to justify our following up the experiment. In the succeeding week we lined our converter nose with bricks made of silicate of soda and limestone, the other with ordinary fireclay bricks, contracting both at this point to a diameter of about 20 inches, or to about one-half the original area. In both cases we perceived at once a great improvement through the reduced size, the converters retaining their heat very much better than before. The slag still adhered to the first-mentioned slightly. It was easily removed by bars, but, unfortunately, usually carried a portion of the very brittle silicate of soda and limestone brick with it, and this form was abandoned on that account. The other converter with the fireclay bricks gave better results, and we have since used them regularly. What little slag adhered could be removed without any material injury to the lining. Al though the common fireclay bricks then used wasted considerably, numerous experiments proved that the amount of silica carried down into the bath from them was too small to do any harm, and as the lining at this part was about 15 inches in thickness, we were able to get regularly from 30 to 40 blows before it got too thin. Thus, as far as the immediate nose was concerned, the difficulty seemed at an end, but we soon found that a great accumulation took place just below the junction of the fireclay bricks with those of the basic material, and also along the sides of the converter, in the form of a ridge of slag and metal left little by little on each turning down for the purpose of sampling. It seemed to us that to remedy this evil the simplest plan was to avoid testing as much as possible, if not altogether. All our results had shown that, notwithstanding the after-blow, the fully blown metal was not nearly so much oxygenated as at the end of the ordinary blow in the hematite process. Numerous analyses gave as the impression that this was due to the presence of manganese in the mixture we were then using, containing as it did about .75 per cent. of this metal, and we found invariably, that when we started with this quantity

there always remained from .1 to .2 at the expiration of the after-blow.

The following analysis show how much more readily (during this part of the operation) the phosphorus is attacked than the manganese:

	At the Drop of the Carbon Flame.	At the end of the After-blow.
	Per cent.	Per cent.
Blow 108 Phosphorus.	.883	.062
" " Manganese..	.443	.111
Blow 136 Phosphorus.	1.090	.044
" " Manganese..	.183	.147
Blow 166 Phosphorus.	.890	.081
" " Manganese..	.435	.194

These, amongst other results of a similar kind, led us for a time to think that it might be possible to eliminate the whole of the phosphorus by increasing the amount of manganese in the charge, and blowing with the spectroscope until the absorption bands—which one of our greatest authorities, Mr. Watts (see "Roscoe's Chemistry," vol. ii., part ii., page 77) on the use of this instrument has attributed to the oxides of this metal—had disappeared, for although our previous experience with mixtures containing .75 manganese had shown us that the bands always disappeared from the spectrum at the drop of the carbon flame, at which from .2 to .4 still remained, we thought it likely (assuming the above theory to be correct) that with a larger quantity we should be able to get rid of the phosphorus before these bands vanished. Accordingly, by means of ferro-manganese we increased the proportion of manganese in charge, No. 165, to about 1.75 per cent. At the drop of the carbon flame, when the bands disappeared, we found the composition to be:

	Per cent.
Sulphur	.118
Phosphorus	.955
Manganese	.817

The sample taken at this period hammered well, but, on testing in the usual way, proved very brittle indeed, and the fracture did not show the characteristic appearance indicating the presence of phosphorus, but resembled that of a very hard steel. On turning up the converter again for a further blow of thirty seconds, certain bands reappeared in the green portion of the spectrum for three or four seconds only; the composition at the end of this period was found to be:

	Per cent.
Sulphur	.155
Phosphorus	.831
Manganese	.612

The sample taken and treated in the same way as before was still exceedingly brittle, and resembled the former one. Again the converter was turned up, and for the space of one or two seconds only these bands again flashed across the spectrum, after which they were not observed during the remainder of the after-blow, although most carefully looked for. At the end of this period the test made was still hard, though much milder than before, and had the following composition:

	Per cent.
Sulphur	.132
Phosphorus	.460
Manganese	.576

The charge was then blown for a further 60 seconds, and as the sample, which was very malleable, did not harden, thinking that the fine crystalline appearance of the fracture, on breaking, was due to manganese, the heat was cast without the addition of spiegel or ferro-manganese. It showed no disposition to rise in the open top ingot moulds in which it was cast, and a tyre 2 ft. 8 inches inside diameter, made from one of the ingots, all of which hammered very well indeed, deflected 8 inches before breaking. Analysis of this steel or ingot iron, which showed that we had not carried the process quite far enough, gave the following composition:

	Per cent.
Sulphur	.114
Phosphorus	.146
Manganese	.440

From these results we drew the following conclusions: that the absorption bands usually seen in the spectrum of the Bessemer flame, are due to carbon, and that manganese bands (very similar in appearance to those of carbon) are apparent only when that metal exists in quantities of about 5 per cent.; and, further, that we could not hope, through

the agency of this metal, to determine upon any fixed point indicated by the spectroscope at which we could safely stop blowing, satisfied that the whole of the phosphorus was removed. But we had before noticed that with regular charges and conditions, the after-blow was of very constant duration, and the results of the blow showed us, not only that with 1.75 per cent. of manganese in the charge, in order to be quite sure of eliminating the whole of the phosphorus, we might safely blow rather longer (without risk of oxygenating) than the time actually required to effect this purpose, and thus avoid sampling, and afterwards, for rails, add a low spiegel or plate-iron to carbonize, but also that, if an ingot iron were required, it could be readily produced by the means described, without any such addition. Want of an iron containing anything like the amount of manganese prevented us from following up these results for some time, but, meanwhile, with mixtures such as we had, containing .75 per cent., we tried the effect of blowing after the addition of the spiegel, until the carbon bands, as seen through the spectroscope, had nearly vanished. The chemical analyses and results of a rolled bar from each of three such blows, tested, gave the following results. (See Table I.)

Three more blows made, amongst others, in the same manner, some weeks afterwards, gave the following results. (See Table II.)

The metal in all cases gave no trouble in casting into ingots (some indeed were cast in open top moulds from the top) and it was very malleable. Specimens of bars from blows 314, 329, 330, and 703 plunged into cold water at a red heat—some of which were afterwards bent and some twisted, cold—are exhibited. Having at length obtained some iron containing about 2 per cent. of manganese, a charge of this was blown alone, and, at the end of the after-blow of 130 seconds' duration, as the test taken was very malleable, and would not harden, the charge was cast into ingots without any addition whatever. The chemical composition of this charge, and the results of the mechanical tests are as follows. (See Table III.)

The heat as before gave no trouble in casting, and the steel was very malleable when worked at a high heat. Samples of the pieces submitted to tensile strain,

TABLE I.

Blows.	C. Carbon by Combustion	Silicon.	Sulphur.	Phosphorus.	Manganese.	Breaking Strain.	Elongation in 10 in.	Reduction of Area.
						tons.	per cent.	per cent.
314	.040	..	.065	.030	.356	24.20	26.875	51.78
329	.050	..	.045	.051	.240	26.48	29.375	65.59
330	.038	..	.069	.035	.266	24.18	26.250	59.04

TABLE II.

Blows.	C. Carbon by Combustion.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Breaking Strain.	Elongation in 10 in.	Reduction of Area.
						tons.	per cent.	per cent.
689	.061	..	.096	.051	.345		Not tested.	
703	.073	..	.091	.027	.370	24.49	31.25	49.79
						24.62	27.50	56.06
705	.101	..	0.70	.047	.468		Not tested.	

TABLE III.

Blow.	C. Carbon by Combustion.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Breaking Strain.	Elongation in 10 in.	Reduction of Area.
						tons.	per cent.	per cent.
748	..	..	.075	.030	.235	23.49	30.00	72.04
						23.49	28 25	70.01
						23.37	27.50	74.12

together with bars plunged into cold water at a red heat, and afterwards twisted and bent cold, as well as ordinary cold bends, are exhibited.

A second charge was treated in exactly the same way, except that, at the end of the after-blow, 15 cwt. of white hematite pig iron were added in lieu of spiegel. The resulting steel gave no trouble in casting, and an ingot hammered to test its malleability, worked very well. Analysis of the steel produced gave the following results:

C.C.	Si.	S.	P.	Mn.
				Per cent.
.55	Not estimated.	.107	.151	.612

It will be noticed that the phosphorus and manganese are higher—the former than it ought to be, the latter than one would have expected to find, after the addition of a non-manganiferous pig; but as the charge of white hematite was melted in a cupola which had only just before contained a 20 per cent. spiegel charge, we think it likely that a small quantity of this must have remained behind and come out with the white iron. With respect to the phosphorus, the mixture was one with which we had had little experience. It was also the last charge from the cupola, and, unfortunately, nearly a ton heavier than it should have been, which circumstance was not observed until it was poured into the ladle. And, although it was blown for 130 seconds after the disappearance of the carbon bands, exactly the same as blow 748, there is no doubt that it was under-blown, as the metal, before the addition of the white iron, contained as follows:

S.	P.	Mn.
.125	.147	.360 per cent.

For some time past, except in the case of the first two or three blows from a new mixture, when samples have been taken to determine the length of the after-blow, we have blown to time, and all testing during the operation has been dispensed with. It is true that our early results were not all satisfactory, but latterly, since we have used a mixture containing about C.C. 4.0 per cent., Si. .5 per cent., S. .2 per cent., P. 1.4 per cent., Mn. 1.0 per cent. in the converter, we have succeeded very well, as the results below will show. During the week ending April 10th, twelve test pieces, taken at random from the week's work, contained of phosphorus as follows:

No.	Per cent.	No.	Per cent.	No.	Per cent.
1	.103	5	.065	9	.111
2	.067	6	.070	10	.054
3	.040	7	.073	11	.074
4	.051	8	.052	12	.048

And in the week ending April 17th, when not a single sample was taken during the operation, except in the case of the experimental blow 748, the average amount of phosphorus contained in 36 blows, all of which were analyzed, was .056 per cent., the highest being .101 per cent., and the lowest .019 per cent. The composition of this quality of steel has been in other respects very regular, the analyses and results of a test-piece, 2 inches long and .533 inches in diameter, being as follows:

Carbon.	Silicon.	Sulphur.	Phosphorus	Manganese.	Breaking Strain.	Elongation.	Reduction of Area.
					tons.	per cent.	per cent.
.40	..	.040	.085	.662	39.75	20.25	31.84

Since the sampling during the operation has been dispensed with, there has

been comparatively little trouble with the slag adhering to the sides of the converter, and the wear of the lining has been practically uniform. As many as 87 blows, representing about 630 tons of steel, have been produced from one lining without any repairs whatever, except, after the 50th blow, new fireclay bricks to the nose; 37 more blows, equal to about 270 tons of steel, were converted in the same lining after renewing the front or blowing side, and putting in a third fireclay nose. At the end of our last week's work (April 17th), during which bricks made of the best pot clay were used for this purpose, instead of being scoured away as had been invariably the case with the commoner ones, they were little the worse for wear, and would, we feel sure, have run for a second week. The vessel bottoms (all made with a mixture of tar and lime rammed round pins) during this same week, averaged 8 blows each, the maximum being 12, and the minimum 4; but this bottom was taken out on completion of the week's work, and was very little worn. With respect to output, during the eight weeks ending April 17th (omitting Easter week, which was a broken one), 3380 tons of steel were made, or an average of 422 tons per week, the largest week being that ending March 27th, when 541 tons 7 cwt. were produced. In conclusion, we think it will be apparent to all that there are no difficulties in the working of the process. We are satisfied that as good steel can be produced by it from phosphoric pig, and quite as regularly as that obtained from hematite in the ordinary ganister-lined converter. We have shown that it is an easy matter to produce a malleable ingot iron, containing practically *no carbon* and very little manganese by this method, which, to say the least, is rather difficult from hematite pig by the old process; and, although our only experiment (results of which we have laid before you) to produce a harder quality of steel from phosphoric pig high in manganese, without the addition of any manganiferous pig, at the end of the operation did not turn out as satisfactory as we could have wished, there appears to us little doubt but that this too will be accomplished, as well as the production of soft steels suitable for boilers and ships' plates, &c., in a similar manner. It is true that our production from one pair of converters has never yet exceeded 541 tons 7 cwt. in one week, but it must not be forgotten that the process is still a new one, and that the plant at our disposal is not of modern construction, nor well adapted to its requirements. These requirements are, in our opinion (on account of the wear of the lining), either additional fixed converters, or duplicates with proper facilities for changing, as well as suitable arrangements for the speedy removal of the large quantity of slag. Under these conditions, in a well-arranged shop, we feel sure that not only as great an output can be obtained by the process as is now being produced in the best English practice in the conversion of hematite, but also that it may be made to equal anything that has ever been accomplished by our friends on the other side of the Atlantic.

AN ANCIENT ROADWAY.

From "The Builder."

ASSYRIAN AND EGYPTIAN MONUMENTS.

LONG before conquering Rome had covered the ancient world with her net-work of military roads, Commerce and War, the sponsors of civilization, had thrown out their lines of communication which bound together the nuclei of culture. The name of one of the earliest cities of primitive times which the Bible makes known to us is Kharran, "the caravanserai," or "road city."* Hither Abraham had journeyed, following, no doubt, the "via publica" of those days, the commercial and military road which bound together the two seats of civilization, the one on the banks of the Euphrates, the other on the banks of the many-mouthed Nile. Few roads can rival, in antiquity or in historic associations, that

*Genesis xi. 31.

ancient pathway of culture which connected the capitols of Babylonia and Egypt, and along which was an ever-flowing stream of intercourse. Centuries ago, in a far remote past, the primitive Semite trader had wandered forth on his long and dreary journey to visit the cities of the "land of the setting sun." Months of traveling of danger from man and beast were before him; but his hand was against every man if every man's hand was against him; and by the doctrine of the survival of the strongest and fittest that pioneer had forced his way westward, westward!

Leaving Babylon we can follow him to the cities of the colony of Assyria-Assur, where the Tigris was crossed.* To Kalah and Nineveh, then both young and dependent on the mother land, so onward he passes until Kharran, the principal resting-place in the upper Mesopotamia, is reached. Here he was among the tribes of the Nahrai, or people of the rivers—a people of whose civilization we know, as yet, but little, but who were always powerful enemies of the kings of Assur. Kharran, Urfa, and the ruins in the Jebel Abdul Aziz, and on the banks of the Khabur, show that this people were no mere confederation of wandering tribes, but were city builders; and recent research in their lands show them to have been the inventors, though perhaps at a late period, of a mode of writing distinct from that of surrounding nations. Kharran, imbued with the influence thus borne to it by this artery of culture, had adopted the Sabean and astrological creed of Babylon, and retained it for centuries after both Nineveh and Babylon had passed away. Indeed, even up to the present time, strange traditions and superstitions, relics of the ancient creed of the people, linger in Kharran. From this ancient city the route passed westward until the Euphrates was reached in the neighborhood of the Hittite city of Carchemish, the emporium of commerce on the river.

Henry Maundrell, one of the earliest English travelers in Syria, who, in 1699, A. D., voyaged from Aleppo to the Euphrates, states that when visiting Jerablis, the site of Carchemish, the natives told him that at or near this point there were traces of an ancient bridge over the river. Of the remains of this ancient means of transit, the traveler states he saw no traces, but the author of this notice, who has recently visited the site, was able to identify the remains which probably gave rise to this idea. About four miles south of Jerablis, on either bank of the river, are to be seen two of the mounds so common in those lands, which evidently mark the sites of ancient ruins. From their position at a point where the river in ordinary seasons would be fordable, it is evident that these mounds mark the site of the forts or towers which guarded the ford over the river where the caravan road crossed.

At Carchemish, this roadway was formed by at least two other caravan routes, one of which followed the west bank of the Euphrates, passing to Babylon; the other, the northern road, which brought down the trade from the districts of the Western Armenia. Of these two roadways, it is not our intention to deal in the present notice, they being better considered in relation to the great Hittite capital.

From Carchemish the Egypto-Assyrian route passed across the plain, to the north of Aleppo, by the cities of Arpad, the site of which is now marked by the mounds of Tel-Erfad, and Khazaz, the modern Azaz. From this point the roadway passed by a narrow ravine through the limestone "Jebel Junneh" into the plain of El-Amk. Hence it passed south through all the cities of the people of Hamath, until at last it emerged by the open pass which divides the northern Lebanon range from the Jebel Ansaria, and emerged on the sea-coast a little to the north of the site of Tripolis. This pass is one of the gates of Northern Syria, and may be identified with "the entry into Hamah." By Arvad and the Phœnician colonies, on the coast, it passed on to the cities of Tyre and Sidon, the homes of the merchant princes of Phœnicia.

It has been necessary thus far to trace the route of this roadway in order the better to understand the historical importance of one of the stations on the route, namely, the rock pass at the mouth of the Nahr-el-Kelb, a pass which was the gateway of Phœnicia. Few

*The ancient name of Assur was "the place of his crossing," or "the city of the ford."

spots in the whole of Syria can rival this rocky pass in historical records or associations, or show so interesting a series of monuments of those whose names are famous on the roll of history.

This historic pass is situated somewhat less than seven miles north of Bierut, at a point where the short but rapid Nahr-el-Kelb, the "Dog River," enters the sea.

The promontory is composed of large honey-combed masses of limestone rock, which are torn and broken into every shape and form by the rude hands of centuries. The gray rocks which wall this roadway being stained in many places by the iron oxide, especially in the places where clefts in the sides have become the channels for small mountain-rills, present a variety of strange tints. Perfectly barren and broken into immense boulders piled one on top of another, like some huge cairn, and stained with the blood red of the oxide, one could not help associating the dull, silent statues, which from the upper ledge of rock looked down on all with a stony calmness, with some mighty conflict which in a by-gone age had raged in this rugged spot.

It was, no doubt, owing to this cairn-like appearance which many of the rocks assumed that Henry Maundrell, in his description of the sculptures in 1697 A. D., suggested them to be possibly the representations of some persons buried there.

Shortly after entering the pass from the south or Bierut end one perceives the statues or sculptured tablets which have rendered the pass of so much interest. They are on the right of the present roadway, and upon a ledge or terrace of the rock which crowns the upper portion of the promontory. The examination of the records has shown that they are arranged in historical sequence, at least as regards those erected by the Assyrian kings; and we may, therefore, consider them in the historical order.

The road by which the pass is traversed is of Roman construction, and passes along a ledge cut out of the face of the cliff and over the sea, its highest point being about 100 feet above the water. This road is now used for the caravans passing by the sea-shore route to Tripolis, Jebeil, and other coast towns. On the upper platform or ledge, which we shall see are the remains of the more ancient roadway, almost directly opposite the highest point of the pass, is the first of the sculptures, a tablet of Assyrian workmanship, and the best preserved of the series. On this same ledge there are also two pairs of tablets, Egyptian and Assyrian, this series of five tablets forming the Southern group.

Following the roadway, we come to the nose or extreme point of the rocky promontory, and here the road takes an abrupt turn east, and passes along the bank of the Nahr-el-Kelb. The descent here is steep and slippery until the ford is reached. Twenty yards down this roadway, and facing the traveler, is a finely-sculptured Assyrian tablet, which is placed to the right of the roadway, on the rock which forms the corner stone between the ancient Assyrian road and the Roman road. From this point to the ford the most ancient Assyrian road and the Roman road coincide. Between twenty and thirty yards further along this roadway, a second pair of Assyrian tablets are to be found cut on the rock, and directly opposite the ford there is an Egyptian tablet, The Roman road is continued for about 600 yards further up the pass, and crosses the river by a bridge.

An examination of these records shows that, as regards the Assyrian tablets, they are arranged in an historical order commencing with the pair of tablets near the ford (Nos. 2, 3), and terminating with that which crowns the highest point of the pass (No. 9).

The table on next page will show this order, together with the epochs to which the sculptures may be assigned.

The first tablet is an Egyptian work, but, unfortunately, it is quite destroyed, having been taken by the French troops forming the army of occupation in 1860–1, during the time of the Druze massacres, to receive an inscription recording their presence. The preparation of the surface necessary for the reception of the new inscription has entirely removed all traces of the ancient inscription. Dr. Lepsius, the German Egyptologist, however, made an examination of the record in 1845, prior to the mutilation, and was then able to trace sufficient inscription to identify it as the

No.	Nation.	Shape.	Date and Remarks.
1	Egyptian.....	Square[1].....	Rameses II. Dedicated to Phtha.[2]
2	Assyrian.....	Square.....	Assur-ris-ilim (B. C. 1140).[3]
3	"	"	Tiglath-pilieser I. (B. C. 1120).
4	"	Round-head.....	Assurnazirpal (B. C. 885).
5	"	"	Shalmanesar III. (B. C. 860).
6	Egyptian.....	Square	Rameses II. Dedicated to Ra.[2]
7	Assyrian.....	Round-head.....	Sennacherib (B. C. 702).
8	Egyptian.....	Square..	Rameses II. Dedicated to Ammon.[2]
9	Assyrian.....	Round-head.....	Esarhaddon (B. C. 681).[4]

[1] The surface of this tablet has been planed and a French inscription cut upon it.
[2] These dedications are assigned by Dr. Lepsius, of Berlin, who examined the tablets in 1845 ("Briefe aus Egypten," 402).
[3] Much worn.
[4] Portion of inscription proves erection in B. C. 672-1.

work of Rameses II., the great Sesostris, and to attribute it as an *ex voto* to the all-wise Phtha. The monuments have also been examined by the late Joseph Bonomi,* and he also attributes them to Rameses. "The most ancient, but unfortunately the most corroded, are three Egyptian tablets; on them may be traced the name of Rameses,† to which period any connoisseur of Egyptian art would have attributed them, if even the evidence of name had been wanting, from the beautiful proportion of the tablet and its cavetto moulding." These Egyptian tablets, Nos. 1, 6, 8, are all similar in shape, being 7 ft. 6 in. high and 3 ft. 8 in. in width at the top, and somewhat more at the bottom. They are surmounted by the overhanging cornice with cavetto moulding, and a feather decoration on the cornice. Upon the lintel of the framework is the winged circle, or solar disc, and the nomens and prenomens of the monarch are inscribed on the jambs. Egyptian records show that these tablets were placed here by the great conqueror, Rameses II., as *ex votos* for his victories over the Kheta and other Syrian allies. The two earlier ones, Nos. 1, 6, which are dedicated to Phtha, and the solar deity Ra, were erected for victories over the Rutennu;‡ but the last one, dedicated to the deity Ammon, is to commemorate the personal triumph of Rameses over the "vile Kheta" and their allies. The tribes of the Kheta or Hittites, the people of Kair Kamasha (Carchemish), of Charibu or Chalibu (Khelbon), or Aleppo, and the southern Hittites, afterwards the Hamathites, the people of Kadesh, had all gathered against the great conqueror. By a great battle before Kadesh, on the Orontes, the allies were defeated and made peace. In this battle the royal commander performed most valiant and superhuman deeds, and the account of his mighty acts are set forth by the poet laureate of that period, one Pentaur or Pindar, the royal scribe, in a long heroic poem.*

We pass now to consider the Assyrian records in this series. First, we have a pair of square-shaped tablets, Nos. 2 and 3, placed side by side about thirty yards above the ford. They represent two royal personages clad in the robes of royalty. The workmanship is evidently that of an early period of Assyrian art, and much earlier than the other sculptures. The reliefs of figures are low and squat in shape, and lack that stately proportion and dignity which we find in the works of either the middle or later empire. There is none of that attention to minute details of features or dress which mark the best Assyrian art. It is, therefore, clear that these works were of a style of art prior to the ninth century before the Christian era. If we examine them closely we find a resemblance in tone to works of which we know the date. There is in the British Museum (Assyrian side room) a statue of an early Babylonian king, Merodach-Nadin-Akhi, who reigned in the twelfth century before the Christian era. The first pair of Assyrian sculptures of which we are

* Transactions R. Soc. Lit., art. iv., by Joseph Bonomi, vol. iii., p. 105, 1839.
† Rameses II.
‡ Or tribes dwelling in the lands forming the basin of the Litany river.

* Third Sattier Papyrus, in the British Museum.

speaking exhibit a marked resemblance to this and other early works,* and we may, therefore, assign these records to the period of the Early Assyrian Empire; that is, the twelfth century before the Christian era. Of the monarchs whose reigns are included in the period of the Early Assyrian Empire, there are two who made expeditions into Syria and penetrated as far as the "sea of the setting sun," namely Assur-Ris-Ilim, B. C. 1140, and his son, Tiglath-Pilieser I., B. C. 1120, a monarch whose reign formed the zenith period of the Early Assyrian Empire.

Of the former of these monarchs we have no lengthy inscription, and his only claim to be considered the monarch who erected one of these statues is his adopting in his inscriptions the title, "the conqueror of the land, as far as the sea of the setting sun." His son, the warlike Prince Tiglath-Pilieser I., has, however, left us a record of his campaigns in the regions of Western Syria, and of his visit to the cedar woods of Lebanon.

In the latter part of his reign, this monarch, having subdued all the tribes of the Nairi, or Upper Euphrates valley, turned his arms against the warlike tribes on the west bank of that river. He crossed the Euphrates, and took the city of Pitru or Pethor, the birth place of Balaam, which was situated at the mouth of the Sadjur; he then advanced against Carchemish, some twenty miles north, and after reducing that city he marched southwest to visit the Lebanon, to obtain cedar, for the decoration of his palaces and temples. He advanced as far south as Arvad or Ardus, where he entered into a ship and slew with his own hand a porpoise.† It is probable that, during this or a subsequent expedition, he visited the cities of Phœnicia, and then erected his statue on this gateway of Phœnicia. Had he been in the neighborhood, as he was when he visited the regions of the cedar groves, and possibly Afka or Apheca, the sacred glen of Astarte, he must have heard of the records of the Egyptian conqueror which were upon the rocks over against the great sea, and his arrogance and pride would prompt him to go and erect similar records of his greatness.

We now move some thirty yards up the pass to the point where the ancient roadway joins the present or Roman road, and on the corner rock here we find another finely cut Assyrian memorial tablet. It is cut on the surface of the rock facing the sea, and is about 7 feet above the roadway. The preparation of the rock, and the work of the tablet itself, at once show it to be the work of a period more advanced in art than that of the tablets below it. It is 6 ft. in height and 2½ ft. in breadth, and the depth of the niche is about 5 in. These Assyrian tablets are cut somewhat deeper at the top, in order that the water which drips down the face of the rock may be carried clear of the upper portion of the sculpture.

The resemblance which this memorial record presents to well known Assyrian monuments enables us very clearly to ascertain the period when it was executed. It may be compared with such monuments as the stelæ from the temple of the war god at Kalakh, or Nimrud, which may be seen in the British Museum. These stelæ were erected by kings of the middle Assyrian empire. In the Assyrian vestibule of the British Museum we have a finely preserved monument of this class, which was erected in the temple of the war god at Kalakh (Nimrud), and which in sculpture is an exact counterpart of the bas-relief now under consideration. This monument was erected by Assurnazirpal, B. C. 885, one of the great monarchs of the middle Assyrian empire. In the side room we have also a similar class of monument erected by Samsi-Rimmon, the grandson of this monarch. The memorial tablets from Kurkh, near Diarbeker, on the Tigris, now in the British Museum, are also of the same class, as well as the rock sculptures at the sources of the Tigris, the headwaters of the Debeneh-Su.

This tablet No. 4 evidently pairs No. 5, which is situated on the higher ledge of rock about 150 yards distant, and we may therefore assign them to the same period. In the case of these two interesting monuments, the historical records, which have been rescued from the graves of Ninevah and other Assyrian towns,

* *Bas-relief* of a king in grey granite in the same room, and the rock sculptures on the Debeneh-Su, near Diarbeker.

† The animal is called the *nakhari*, "blowing animal," and is probably the porpoise.

afford us much interesting information, and enable us to fix the period of their erection. The lower of the two we may certainly assign to the great conqueror Assurnazirpal, B. C. 885, who subjugated the whole of Western Asia to the Assyrian rule.

From the great historical inscription which covers the pavement slabs of the rich war temple at Kalakh, we learn the details of the campaign which this statue commemorates. "On the 8th day of the month Iyar [April]" probably in the year B. C. 870, the Assyrian monarch started from the royal city of Kalakh on an expedition, the ostensible object of which was the subjugation of the Hittite power and the capture of Carchemish. After following the ancient military road, the route of which we have traced, he came to Carchemish, the king of which submitted. His intention now was to proceed to the Lebanon to cut cedar for his extensive building works at Nineveh, and to extort some tribute from the rich Phœnicians.

"In these days I occupied the sides of the mountains of Lebanon (Labnana).
To the great sea of the west I approached.
My arms upon the great sea flashed.
To the gods I sacrificed, and tribute of the princes of the sea shore of the lands of Tyre, Sidon, Gebal [Jebeil], Makullat, Mázai, and Kaizai of the Phœnicians of Arvad, in the midst of the sea I received."

This tribute, we are told, consisted of all the wealth of Phœnicia. The king then speaks of the cutting of cedars in Lebanon; and it was evidently during his campaign that his statue was erected over against the great sea. We may, therefore, safely assign this tablet to the great king Assurnazirpal, whose statue from Nimrud it so closely resembles. Before proceeding to describe this pair of statues, we will notice the historical data with regard to the erection of the second of the pair—namely, that which is on the platform of rock above the present roadway.

This statue we may certainly attribute to Shalmanesar III., the son of Assurnazirpal. This monarch came to the throne of Assyria in B. C. 860, and at once commenced to carry on the warlike policy of his father. In his first year, B. C. 859, he marched forth on a tribute gathering expedition, and after visiting the cities on the banks of the Khabour, Carchemish, and of Hittite cities, he came to the cities of the sea coast.

"[To] The upper cities of the west and the sea of the setting sun. . . . .
The tribute of the kings of the sea coast I received on the shores of the broad sea. . . . .
I descended. An image of my lordship. The record of my name for ages I made. Over against the sea I placed it."

Such is the record of the erection of this royal statue, which was to be a record of the king's name. Little did he think that for over twenty-seven centuries it would stand as a record of the deeds which he had done.

The king is clad in the long sleeveless robe, or "kamis," richly embroidered and fringed, and on his head is the royal tiara, or cap. These caps may to this day be seen worn by the Kurdish chieftains, but now made of a species of felt; whereas at that period the material was probably of metal-work. The right hand is extended in adoration towards sacred symbols which occupy the corner of the background.

These Assyrian memorial tablets differ materially from those of other nations, yet they have contributed much to the adoption of this kind of memorial by the Hittites, Lydians, and other nations.

That wonderful brazen war panorama which has been restored to us in the bronze gates from Ballawat has brought before us an interesting tableau connected with these memorial stelæ. We have there the representation of the erection of one of these memorial tablets upon the rocks over against "the great sea of the rising sun," the sea of the Nairi, that is Lake Van. In that scene we have before us the ceremonial which took place, and we see how important was the event considered to be, how royal pomp and religious ceremony were all brought to bear upon the work and to contribute to the glory and honor of the great king. Priests with portable altars are standing before the statue and burning incense, and victims are being brought forward to be slain. The soldiers or attendants are seen casting portions of a victim already offered into the sea, to propitiate the gods of the deep. On the occasion of the erection of one of these royal *ex votos*, not only were offerings made to the newly erected sculpture, but also to those which had

preceded it, so as to pacify and honor the manes of the ancestors of the king.

This last tablet, No. 5, the monument of Shalmanesar III., has been erected alongside of an Egyptian one. The late Mr. Bonomi suggested that the Assyrians had availed themselves of the surface of the rock which had been prepared by the Egyptians. This may be possible; but there also seemed to be a special motive in the juxtaposition. We find Nos. 5, 6, placed side by side, and Nos. 8, 9. No. 5 was, as we have seen, the work of Shalmanesar III., and No. 9 that of Esarhaddon, both of which monarchs in their wars had come in contact with the hostility of Egypt. The former had only, at the time at which his statue was erected, been opposed to the intrigues of Egypt among the Hittites, but the latter had come into actual and victorious conflict with the serpent of Old Nile, and had erected his tablet here to commemorate victory. It is, therefore, more probable that the juxtaposition is the result of this feeling of arrogance towards Egypt.

The two Egyptian tablets in this upper road have been at some time protected by bronze doorways, in a similar manner to the trypticles in churches, and the holes in which the sockets of the hinges were inserted are yet to be seen.

The tablet No. 7, which is placed a few yards further up the cliff, south of the Egypto-Assyrian group (Nos. 5 and 6), has, by nearly all who have examined it, been assigned to Sennacherib (B. C. 705). The examination of this sculpture shows that we have now a work of a more advanced art period than that which we meet with in either of the other tablets. The framework which encloses the sculpture is larger and better proportioned, the sizes being 7 ft. 3 in. high, and 3 ft. 8 in. wide. The workmanship shows it to belong to the best period of Assyrian art, and although there is no record of its erection by Sennacherib to be found in the inscriptions, its resemblance to the Bavian and other records of that king show it to be a work of his reign. Sennacherib visited Syria and Palestine at least three times in his reign. In B. C. 703-2, he defeated the Palestine and Egyptian armies at Eltekeh, an account of which expedition is found in the Taylor cylinder. There were probably at least two other expeditions against Palestine later in his reign, as shown by the fragmentary records in the British Museum.

In this text of the Taylor cylinder there is no mention made of the erection of a royal statue on the shores of the great sea, but this does not preclude the possibility of such an event. In the inscriptions of Sennacherib and his successors a more florid style of literature is in vogue than in the time of Shalmanesar and the kings of the Middle Empire. The former style was a diurnal one; each halt, each river crossed, and almost every event of the march, with most accurate statistics of the tribute, &c., are given, but in the texts of the time of Sennacherib a more grandiloquent and general style is adopted, and these minute details are omitted. The increase of bureaucracy had formed a style which left these details to the terra-cotta despatches and blue books in the War or Record offices of Nineveh, while gilded and verbose abstract was given on the record cylinders of the king.

The last group of these interesting monuments of antiquity consists of a pair of tablets, one Egyptian and the other Assyrian. The first of these, No. 8, is dedicated to the Theban Ammon, and was erected in honor of that deity by Rameses II., after his great victory over the Kheta and their allies; the second is an Assyrian tablet, similar in style to the three last described. This monument is the one of which Henry Maundrell, who visited the pass in 1697 A. D., states "there is one of the figures that had its lineaments and inscriptions entire. A cast of this sculpture was obtained by Mr. Joseph Bonomi in 1834, and was presented to the British Museum by the Duke of Northumberland."*

In the possession of this copy the British Museum authorities are fortunate, for they now have in it a much better copy than the original monument. Forty-five years of exposure to the wear of the sea and air have obliterated much that was visible, and one failed to recognize portions of the inscription which are known to be extant in the cast. In the upper left-hand corner of

*It is in the Koyunjik Gallery.

the tablets are a group of sacred emblems, the sun, crescent moon, the seven stars, or pleiades, and other religious emblems. The royal features, hair, beard, and headdress, the portion of the robe not obliterated by exposure, all show the greatest attention to detail, and the sculpture when perfect must have been a fine example of Assyrian workmanship. Some of the remaining portions exhibit an amount of fine carving rarely expended on rock sculptures, which are usually bold in outline and scant in detail. Strange to say, in direct opposition to all this extra attention to workmanship on the part of the Assyrian artist, the selection of the portion of rock exhibits a most decided mal-judgment. A portion of rock has been chosen which is covered with a thin superficial layer of fine stone. The cutting of the *bas-relief* and inscription has worn this extremely thin; the result is that in exposed portions the layer has disappeared, taking with it large portions of sculpture and text.

The sculpture represents the king standing arrayed in royal robes, and wearing the royal tiara, or headdress, richly decorated with floriated rosettes. The right hand is elevated towards the sacred emblems, and the king appears to hold in his hand a couple of feathers. We now turn to the fragmentary inscription which covers this interesting record to see what royal and kingly personage is here represented. The occurrence of such names as Assur-akhi-iddira, Esarhaddon, Sin-akhi-irba, Saincherib, together with the royal titles of "King of Babylon," "King of the Lands of Egypt and Ethiopia," and the mention of an expedition against Tarq or Tirhakah, ending in the sack of "Memphis, his royal city," furnish sufficient detail to enable us to form an accurate conception of the date of the tablet.

By these titles and data we may see that the statue represents Esarhaddon, the third and faithful son of Sennacherib, who came to the throne of his father in B. C. 681, and reigned until B. C. 668, when his son, Assurbanipal succeeded him.

Ever since the rise of the Ethiopian or twenty-sixth dynasty in Egypt, there had been a rapidly increasing opposition between the two great powers of the East. Sargon had come in contact with the king (Siltan) of Egypt; Sennacherib had suppressed the revolt in Palestine due to the intrigues of Tirhakah; and now again, in the reign of Esarhaddon, the messengers of Egypt were raising revolt in the lands on the borders of the Western Sea. From a small inscription, now in the British Museum, we learn that in his tenth year (B. C. 672.1)* Esarhaddon had news of a revolt in Tyre. In the early part of his reign the intrigues of Egypt at the court of Sidon had led to its destruction by the Assyrians, and now Tyre, who had benefitted by the fall of her sister city, was yielding to the flattering solicitations of Egypt.†

By the defection of Tyre the Egyptian king had hoped to cause a block on the Assyrio-Egyptian road, and thus give time for a more effective resistance in Egypt. Esarhaddon, however, lost no time, but marched direct across the Syrian desert, probably by the Damascus caravan route, and entering Palestine near the city of Aphek (*Apku*), on the borders of Samaria, he despatched one contingent of his army to hold in check Tyre, with the other he marched direct into the heart of Egypt. This well planned campaign ended in the defeat and flight of Tirhakah and the capture of Memphis and many other Egyptian cities. Egypt was divided into twenty-two satrapies under governors dependent on the court of Assyria, and the Assyrian king returned with an immense booty. On the return march, which followed the Assyrio-Egyptian road, tribute was gathered from the principal Palestine and Phœnician cities, and also from the kings of Cyprus.

It is an interesting fact that the inscription at *Nahr-el-kelb* commences with an enumeration of the titles of Hea or Oannes, the god of the sea, which seems to indicate that this is an *ex voto* for a successful sea voyage. It is possible that the Assyrian king had prepared to bring the rich spoils of the Egyptian campaigns and the tribute of Tyre and other cities in ships taken from Egypt

*Transl. by W. St. C. Boscawen, Trans. Soc. Bib. Arch., vol. iv., pp. 84-97.

†On the fall of Sidon, a convention granted by the Assyrian king had ceded Dor Accho (Acre) and Gebel (Jebeil) to Baal, King of Tyre, the pass of the Nahr-el-Keib would therefore be at that time in the Phœnician hands.

rather than by the difficult overland route.

From these facts we may conclude that this statue was erected in B. C. 670, to commemorate the successful termination of the war in Syria and Egypt. With this statue of the conqueror of Memphis ends this historic sculpture gallery.

By a strange chance coincidence this last record is placed by the side of an Egyptian tablet, recording the victories of one of the greatest of the Pharaohs. With Egypt in its glory it begins; with fallen and crushed Egypt and captured Memphis it ends. How plainly now do we see in the small act of thus placing his statue close alongside the Egyptian's record, the proud assertion of the victor's power.

"O Heaven, that one might read the book of fate,
And see the revolution of the times!"

Rome has left here a record in this pass to tell of her dominion, as near the bridge may be seen a rock-cut tablet bearing an inscription of Marcus Antoninus (A. D. 179), who made the lower or Roman road.

Last in the series of records of great men and mighty deeds we have an Arabic inscription of Sultan Selim I. (A. D. 1517), who repaired the bridge which crosses the stream.

Thus, in this rocky pass, under the slopes of cedar-famed Lebanon, there are preserved the records of the conquerors of the East for more than thirty centuries,* and by their aid we can form some idea of the grand armies which have in the past trodden this most ancient of roadways.

* This includes the French occupation in 1860. The records extend from 1350 B. C. to 1860 A. D.

IRON AND STEEL AT LOW TEMPERATURES

By JOHN JAMES WEBSTER, Assoc. M. Inst. C. E.

From the Proceedings of the Institution of Civil Engineers.

I.

From the earliest days of iron-bridge building, some forty years ago, to the present time, the opinion of engineers as to the condition of iron and steel at temperatures below the freezing point of water has been much divided. The general impression appears to be that both materials are, to a certain extent, affected when subjected to the action of frost, by becoming more crystalline in their structure, thus making them incapable of bearing the same strains they could sustain at a higher temperature. This impression has probably arisen from the fact of so many rails, tires, axles, chains, &c., having broken during severe winters. If, however, the returns issued by the Board of Trade be examined, it will be found that the majority of recorded fractures do not occur in winter; and even if they did, it has been often and justly held, that the fractures may have occurred not from the action of frost on the materials, but from other causes, such as the rigidity of the frozen road, restrained contraction of the materials, formation of ice in crevices, &c. On the other hand, it must be remembered, that in those countries where the winters are longer and more severe than in Great Britain, no such records of fractures are kept, or possibly it might be found that they occurred more frequently in winter than in summer. Again, some of the fractures which are now recorded as having occurred at ordinary temperatures, may possibly have had their origin during a severe frost, and after the materials had withstood the working strain for some time, may finally have given way during perhaps one of the hottest months in the year, thus showing the impossibility of forming any opinion of value on what is merely circumstantial evidence.

Many eminent engineers gave a large amount of evidence on this subject before "the Commissioners appointed to inquire into the Application of Iron to Railway Structures," and all were of opinion that both wrought iron and cast iron were weaker when at temperatures

at or below the freezing point. The evidence on this head was, however, nearly all founded on opinion, and not from direct experiments. The principal experiments mentioned were those of the late Sir William Fairbairn, and of Mr. Brunel. The latter, when giving evidence of the possible change of structure of iron from continued vibrations, said, "I should mention that I have tried temperature also, freezing mixtures and warmth, and that the difference is decided; the iron in a cold state breaks shorter and shows more crystalline fracture than the same iron warmed a little; and, I have no doubt, you might take a bar 10 feet long and break it into ten pieces, and make them all in turn crystalline and fibrous according to the temperature." A little further on in his evidence he says, "I would just wish to say, in reference to an answer which I gave to a former question, that I believe that cast as well as wrought iron varies in its strength with the temperature." No detail of the experiments referred to were put in evidence, and the author has not been able to find any record of them.

Since that time numerous experiments have been made to ascertain, if possible, the real condition of iron and steel at low temperatures, but with no satisfactory results; for if the results were summarized, such a mass of contradictory evidence would be found, that the question would appear almost as far off solution as ever.

Many of the experiments have been of the crudest form, and need not be considered, although it is astonishing what strong opinions have been formed and expressed by some engineers on no stronger evidence for the foundation of their belief than perhaps the breaking of a few bars of iron with a sledge hammer in winter, or other trials equally rough and valueless. The most important experiments on the subject, are those of the late Sir William Fairbairn, M. Knut Styffe, and Mr. C. P. Sandberg, Assoc. M. Inst. C. E., and as the results obtained by them give important evidence on the question, it is proposed briefly to consider them.

EXPERIMENTS BY SIR WILLIAM FAIRBAIRN.

The first series of experiments by Sir William Fairbairn were those made upon cast iron only, and they formed part of his evidence before the Commissioners. The experiments were made to ascertain the transverse strength of bars 1 inch square when placed on bearings 4 feet 6 inches apart; two bars being tested at a temperature of 26° Fahrenheit, four bars at 32°, two bars at 190°, and two bars at 600° Fahrenheit. As one-half of the bars were of cold blast iron, and the other half really of hot blast iron, the experiments were reduced to a comparative test of three bars at the low temperatures, and one bar at the higher temperature.

The next trials, given in the same evidence, were made to ascertain the resistance of cast iron bars to impact, and were under precisely the same conditions as the above, as far as regards the temperatures and number of bars tested. The summary of his evidence on these points were as follows: "On the whole, we may infer that cast iron of average quality, loses strength when heated beyond a mean temperature of 220°, and it becomes insecure at the freezing point, or under 32° Fahrenheit."

The next series of recorded experiments by Sir William Fairbairn are those in a paper read by him before the British Association in 1856. In this instance, wrought iron plates and bars were tested, and in the summary of results obtained at the different temperatures, one plate and one bar only are given as being tested at 0° Fahrenheit, and six plates and three bars at temperatures rising from 60° to 435° Fahrenheit. The test strips were broken horizontally in a single lever machine, having a scale pan at one end of the lever, but without any of the fine adjustments which are fitted to the machines of the present day. The results led him to believe "that iron bars or plates were not materially affected by cold." These experiments were evidently carried out more with the intention of ascertaining the strength of iron at high than at low temperatures, and, although they were conducted and recorded as accurately as possible with the then existing apparatus, the author is of opinion that the experiments on both cast and wrought iron were of far too limited a character to justify any definite conclusions being drawn as to the real condition of iron at low temperatures.

EXPERIMENTS BY M. KNUT STYFFE.

By far the most elaborate and carefully conducted experiments upon iron and steel at low temperatures are those by M. Knut Styffe, Director of the Royal Technological Institute at Stockholm. Of these a full account, with the results and conclusions arrived at, is published in a book which has been translated by Mr. C. P. Sandberg, Assoc. M. Inst. C. E.

The experiments were carried out in 1865, for the information of the Swedish Government Committee appointed to report upon the relative value of steel and iron in the manufacture of railway materials. The materials experimented on included a large number of samples of Swedish iron and steel, Krupp's steel, Lowmoor, Cleveland, and Welsh iron, and some bar iron from the Earl of Dudley's works. The principal object of M. Styffe's researches was to establish the exact limit of elasticity of each sample, considering this to be the true measure of its strength; but a large number of the tests were made to ascertain the tensile strength of iron and steel at very low temperatures. M. Styffe came to the following conclusions:

1. "That the absolute strength of iron and steel is not diminished by cold, but that even at the lowest temperature which ever occurs in Sweden, it is at least as great as at the ordinary temperature (about 60° Fahr.)."

2. "That at temperatures between 212° and 392° Fahr., the absolute strength of steel is nearly the same as at the ordinary temperature; but in soft iron it is always greater."

3. "That neither in steel nor in iron is the extensibility less in severe cold than at the ordinary temperature; but that from 266° to 320° Fahr. it is generally diminished, not to any great extent, indeed, in steel, but considerably in iron."

4. "That the limit of elasticity in both steel and iron lies higher in severe cold; but that at about 284° Fahr. it is lower, at least in iron, than at the ordinary temperature."

5. "That the modulus of elasticity in both steel and iron is increased on reduction of temperature, and diminished on elevation of temperature; but that these variations never exceed 0.05 per cent. for a change of temperature of 1°.8 Fahr., and therefore such variations, at least for ordinary purposes, are of no special importance."

These results are contrary to generally received opinions, showing that, if anything, iron and steel are actually stronger at low temperatures. The experiments were conducted most carefully, and the results recorded very minutely, but one or two points are, perhaps, open to discussion. For instance, the sectional areas and extensions are given to $\frac{1}{10000}$ inch, and although an accurate measuring rod, regulated by fine micrometer screws, was used, yet, in direct measurements, no matter how delicate the apparatus, there is always a liability of errors, and it is only by such a device as that adopted by Professor Kennedy, in his testing apparatus at University College, that such measurements can be relied upon. The sections are stated to have been obtained with callipers, but even supposing they were vernier callipers, it seems doubtful if such minute measurements could be taken to four places of decimals.

The bars were about $\frac{1}{2}$ inch round or square, and were filed down to about $\frac{1}{8}$ inch square for a length of from 4 to 6 inches in the center. It is to be regretted that the portion of the bar under the actual test was of so small a sectional area, as no doubt, when such small sections are used, errors are liable to occur; for supposing the bars to have been filed to such a nicety, if they were not perfectly homogeneous—a most probable condition—the percentage of error would be far greater than if the bars had been of larger section. This error would have been reduced had more samples of the same class of iron been tested; but the tables show that, although nine bars of iron and six bars of steel were tested at the low temperatures, in no case were more than two of the same quality of iron or steel experimented upon, the same number of bars being tested at the high temperatures to make the comparison.

The next most interesting series of experiments on this subject are those by Mr. C. P. Sandberg, which may be briefly described as follows:

EXPERIMENTS BY MR. C. P. SANDBERG.

Mr. Sandberg was of opinion that, although the experiments of M. Styffe might prove that iron and steel at low temperatures were not reduced in tensile strength, yet when subjected to sudden blows or shocks, they might possibly be affected by the action of severe frosts; and in order to ascertain this point, he made a large number of experiments which are fully described in the appendix of his translation of M. Styffe's work.

These experiments were made in Sweden in 1867, with seven iron rails from Aberdare, five rails from De Creusot, and two Belgian rails. The rails were all 21 feet long, and were broken by being placed on two granite blocks 4 feet apart, resting on a solid granite foundation, and allowing a ball weighing 9 cwt. to fall upon the rail between the points of support from varying heights. The two broken portions were afterwards tested in a similar manner; the tests were made at temperatures of 10°, 35°, and 84° Fahr.

From the results of his experiments, Mr. Sandberg came to the following conclusions, viz.:

1. "That for such iron as is usually employed for rails in the three principal rail making countries (Wales, France, and Belgium), the breaking strain. as tested by sudden blows or shocks, is considerably influenced by cold; such iron exhibiting at 10° Fahr. only from one-third to one-fourth of the strength which it posssesses at 84° Fahr."

2. "That the ductility and flexibility of such iron is also much affected by cold, rails broken at 10° Fahr. showing on an average a permanent deflection of less than 1 inch; whilst the other halves of the same rails, broken at 84° Fahr., showed a set of more than 4 inches before fracture."

3. "That at summer heat the strength of the Aberdare rails was 20 per cent. greater than that of the Creusot rails; but that in winter the latter were 30 per cent. stronger than the former."

There can be no doubt of the accuracy of the results of these experiments. Is it equally certain that the decrease of strength recorded was entirely due to the action of the frost? The author is of opinion that it is not, and for the following reasons:

It must be noticed that nearly all the bars tested at the lower temperature were the 21-feet lengths, and those tested at the high temperature the short lengths; but if the bars had been all of the same length, different results would most probably have been obtained. The experiments made by Mr. Hodgkinson for the Royal Commissioners, proved conclusively that in the case of a bar subjected to impact, the strength did not increase with the reduction of the distance between the points of support, as in the case of a statical load, but that the strength actually decreased, the force evidently being taken up in bending the bar, and in overcoming its inertia. This conclusion is given as follows in the Report of the Commissioners:

"The experiments in Tables I., II., III., IV., V. afford illustrations of some of the conclusions in the large generalization of Dr. Young, deduced from neglecting the inertia of the beam (Nat. Phil., Lecture XIII.). 'The resilience of a prismatic beam, resisting a transverse impulse, follows a law very different from that which determines its strength, for it is simply proportional to the bulk or weight of the beam, whether it be shorter or longer, narrower or wider, shallower or deeper, solid or hollow. Thus, a beam 10 feet long will support but half the pressure without breaking, as a beam of the same breadth and depth only 5 feet in length will support; but it will bear the impulse of a double weight striking against it with a given volocity, and will require that a given body should fall from a double height in order to break it.'"

In Mr. Sandberg's experiments, the bearings were 4 feet apart in every instance, but the great overhang at each end, when a long rail was being broken, converted it into a continuous girder, thus virtually reducing this distance. Taking these things into consideration, it would appear that the differences observed in his results were, to a great extent, owing to the differences in the length of the rails.

It will thus be seen how fractures of rails in a permanent way are more likely to occur in severe winters than in the warmer months, the unyielding nature of the ground reducing the actual bearing of the rails to the conditions of a beam

fixed at both ends, and having a span equal to the distance between the chairs, instead of having, as under ordinary circumstances, a much longer span, varying, of course, with the nature of the ground upon which they are laid.

Having briefly reviewed the results obtained, and the conclusions arrived at by different authorities, the author ventures to submit a number of experiments he has made, as a contribution towards the solution of this question.

EXPERIMENTS BY THE AUTHOR.

The materials tested in these experiments were wrought iron, cast iron, Bessemer steel, and best cast steel, as well as malleable cast iron, now extensively used for pitch chains, double links of dredgers, and other important purposes where wrought iron and steel were formerly employed.

As the results are intended merely to show the comparative strength of the materials when at ordinary temperatures, and when under the action of severe frost, the numbers recorded must not be taken to represent the actual strength of any particular class of iron or steel; for the quality of the material was not of so much importance in the experiments as the fact of having all the bars in one set as nearly alike in every way as possible, although in many instances high results were obtained. In the first experiments the comparative tensile strengths of wrought iron, malleable cast iron, and Bessemer steel, were observed when at ordinary and at low temperatures, twelve bars of each being tested, six each at 50°, and six each at 5° Fahrenheit, the latter temperature being considered a fair representation of the severest frost likely to be experienced in this country.

The experiments were made to ascertain the comparative transverse strength of twelve bars of cast iron, six being tested at 50°, and six at 5° Fahrenheit. Cast iron was the only material experimented upon for transverse strains, as it is almost impossible to test wrought iron or steel in this manner, owing to the great deflection of the bars before fracture; it is only in the common material that fracture will take place.

The succeeding experiments were with a view to observe the comparative effects of impact on bars of wrought iron, malleable cast iron, ordinary cast iron, and cast steel, twelve bars of each material being tested, six of each at 50°, and six of each at 5° Fahrenheit.

In all cases, the greatest care was taken to obtain each set as nearly alike as possible. The samples of wrought iron or of steel bars in each set were cut from the same bar, or two bars, rolled at the same time. When the samples were taken from two bars, to reduce any error which might possibly arise from one bar not being exactly the same as the other, three samples of each were tested at the low temperature, and three of each at the ordinary temperature.

The cast iron test bars were all run from the same ladle, a large one being used for the purpose, that there might be an excess of metal after the operation of casting. The malleable samples were cast together, and annealed in the same oven.

All the bars tested at the low temperature were buried in snow for two or three days. Previous to being tested they were covered for about three hours with a freezing mixture of snow and salt, and were then taken direct from this mixture to the machine. While the test was being made they were kept surrounded with the mixture by being placed in a specially constructed box (Figs. 7 and 8).

DESCRIPTION OF THE TESTING APPARATUS.

The apparatus employed for determining the tensile and transverse strains of the different samples, was the testing machine* belonging to the Hull Dock Company, kindly placed at the author's disposal by the courtesy of their Engineer, Mr. R. A. Marillier, M. Inst. C. E.

This machine consists of a series of compound levers, the straining power being applied by a small hydraulic pump. The general arrangement of the apparatus is shown on Plate 7, Fig. 1 being the side elevation. H is the hand pump which forces oil from the tank B into the cylinder C, acting on the top side of the piston, fitted with cup-leathers, and having a jaw forged on the piston-rod head, through which passes the pin D.

*The testing machine was constructed by Messrs. Bell, Lightfoot & Co., Walker Engine Works, Newcastle-upon-Tyne.

The test bar E is held at the bottom by this pin, another pin F passing through the bar at the top, and connecting it to the two links G, which are hung on knife edges fixed to the lever H, coupled by the links J to the top lever K. To

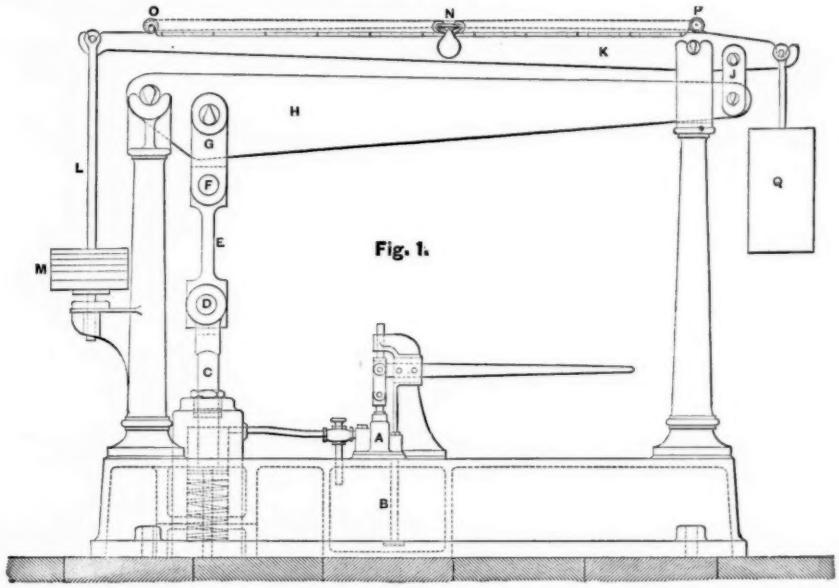


Fig. 1.

this lever is hung the rod L, on which are placed the weights M, for ascertaining the test loads; the total leverage being 160 to 1. The top edge of the lever K is graduated up to 1 ton, and is fitted with a riding weight N, which is moved along by a cord passing over the fixed pulley O, and a small hand wheel and pulley P. The weight of the levers is counterbalanced by the weights Q, and, as all the connections are made by knife edges, the friction is reduced to a minimum, a trifling weight being sufficient to turn the balance. A spiral spring below the piston forces it back into position after a bar is broken. This plan works satisfactorily, the only disadvantage being the increase of pressure in the cylinder, necessary to compress the spring, which varies with the extension of the test bar.

When tests are made with transverse strains, the cast iron crosshead A, Figs. 2 and 3, is suspended from the lever H,

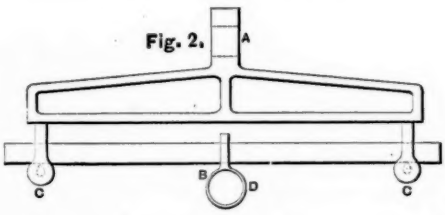


Fig. 2.

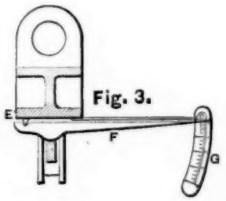


Fig. 3.

the test bar B being placed on the knife edges C; a clip D, with an internal knife edge, rests on the center of the bar, and is attached to the cross head of the piston by the pin D, the pressure being then applied by the hand pump as

before. A small stud E, having its end filed to a knife edge, is screwed into the crosshead A; and against this, on the top edge of the test bars rests a light rod E, used as an indicator of the deflection; the real amount of this being multiplied ten times, and read off on the graduated quadrant G, which is set at zero at the commencement of each test.

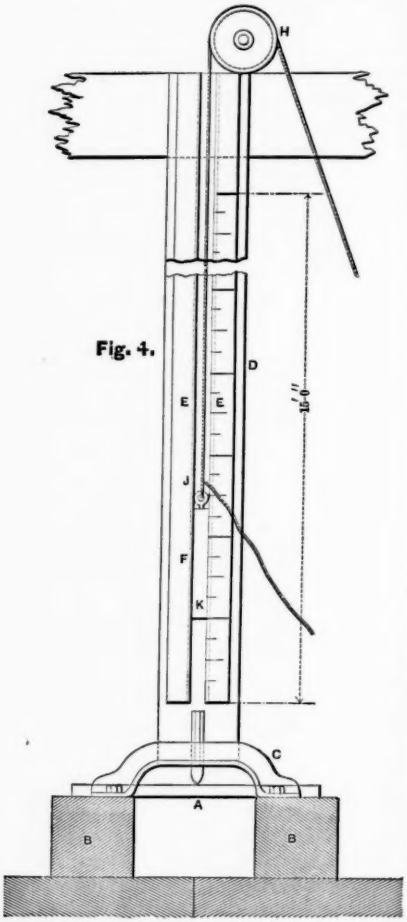


Fig. 4.

In making the tests with transverse strains, the riding weight was used to ascertain the loads up to 1 ton, and, if the bar did not break, was brought to zero, and a weight representing 1 ton placed on the rod L, the riding weight being then used again up to the breaking point. The deflections were not self-registering, but were carefully noted as the loads were increased.

The apparatus used for determining the effects of temperature on bars, when subjected to impact, is shown in Figs. 4 and 5. The bar to be tested, A, was placed upon two heavy cast iron blocks B, kept in position by means of two angle-irons C, 4 inches apart, with distance blocks between. On the bottom edge of the back angle-iron rested a 2-inch plank D, 18 feet long, by 12 inches wide, bolted to the angle-iron at the bottom, and to a cross beam of the building at the top. To this plank were fixed guides E, for the falling weight F to run between. Between the angle-irons C were bolted the distance blocks G, shown to an enlarged scale in Fig. 6; between these again was placed a steel dolly 2 inches square, having an edge the width of the bar, and rounded to a radius of $\frac{1}{2}$ inch; the dolly rested on the top of the test bar, the force of the falling weight being transmitted through it. To the front of the dolly was screwed a piece of hard wood, a space being left in the distance-blocks for it to work freely without touching the blocks or the angle-iron, and to this wood was fixed a strip of paper, a fresh piece being used for each test bar, and on it was carefully marked the permanent set after each successive blow. The falling weight was a piece of 3-inch-square iron, weighing 40 lbs.; it was lifted by a rope passing over a pulley H, and released at any height, by pulling a light cord attached to a simple disengaging

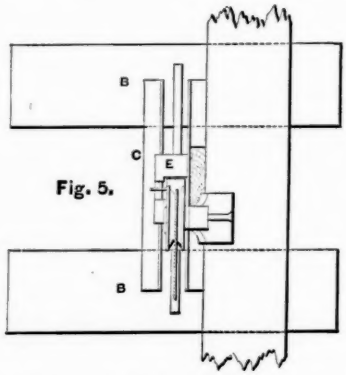
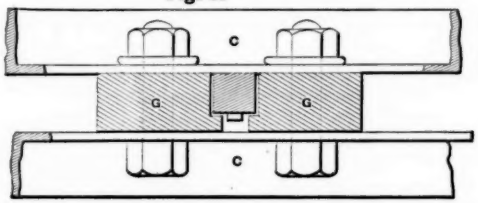


Fig. 5.

hook J. The guides E were marked every 6 inches up to 15 feet, which was the limit of the fall, a small pointer K being fastened to the falling weight. A record of the height of each blow was kept, and the deflections read off the slip of paper were placed opposite to the corresponding fall, as shown in Tables V., VI., VII. and VIII.

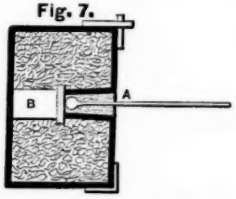
When the bars were tested at low temperatures, they were taken from the freezing mixture, in which they had been lying for three hours, and placed in position in a wooden box fitted between the iron

Fig. 6.



blocks, the box being filled with a freezing mixture of snow and salt. The bar was kept covered during the whole time the test was being made. At the back of this box a small recess was fitted, A in Fig. 7 and 8, and arranged so as to press against the test bar, being kept in position by a stop B, fixed on the other side; thus a portion of the bar was kept

Fig. 7.



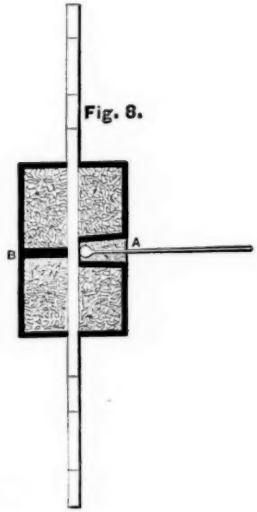
dry, and the recess free from the action of the mixture in the box. Into this recess was inserted the bulb of a thermometer touching the bar, and packed behind with cotton wool to exclude the external atmosphere. By these means a near approximation to the temperature of the bar was obtained.*

Although the freezing mixture was at zero, the temperature of the test bar was found in every case to be about 5° Fahrenheit, the difference of the two temperatures being due, no doubt, to conduction through the connections of the bar with the testing machine.

EXPERIMENTS ON WROUGHT IRON BARS SUBJECTED TO TENSILE STRAINS.

The first experiments were made with twelve flat bars, six of them being originally 6 inches broad by $\frac{1}{2}$ inch thick, and the others $3\frac{1}{2}$ inches by $\frac{1}{2}$ inch. They were rolled from the same pile, but to prevent any error arising from the difference of the two sections, three bars of

Fig. 8.



* The author originally intended to have observed the temperature of the test bars by a thermopile and galvanometer, one cone of the thermopile being placed in the recess next the exposed portion of the bar, and the other cone next a Leslie's cube; the difference of the temperatures being observed by the position of the reflected light of the galvanometer; but as he was disappointed in not having the apparatus completed in time for the experiments, he was compelled to use the thermometer. Although this apparatus would have been more sensitive to the variations in temperature, the recorded temperatures may be considered sufficiently accurate for the object of the present experiments. The thermometer was allowed to remain next the bar for about twenty minutes before the observations were taken, the bar being covered the whole of the time with the freezing mixture.—J. J. W.

each were tested at the low temperature, and three of each at the ordinary temperature. After the holes for the coupling pins had been bored, great care being taken that a line joining the two centers passed exactly through the center of each bar, they were placed upon a mandrel, and all shaped together to a width of $1\frac{1}{2}$ inch for a length of $6\frac{1}{2}$ inches in the center of the bar, a uniformity of the sections being thus ensured. Although pins were used for attaching the test bars to the machine, the plan of using serrated steel wedges or "dogs" is far preferable; for by that means a large amount of skilled labor is dispensed with in preparing the test bars, and there is not the same chance of errors arising from the direction of the tensile strain not passing through the center line of each bar. After leaving the shaping machine, each bar was carefully examined and numbered; and on the center line, which was marked with a fine scriber, two center punch dots were made at a distance of $6\frac{1}{4}$ inches apart, this length being the one taken to ascertain the ultimate extension. The distance adopted by various authorities is generally either 6, 8, or 10 inches, but the $6\frac{1}{4}$-inch gauge is a most convenient one, for by adopting it the percentage of elongation can be read off at once, every $\frac{1}{16}$ inch being equivalent to 1 per cent.*

As it was intended to observe, in addition to the ultimate extension, the amount which took place at different portions of the test bar, the distance of $6\frac{1}{4}$ inches was divided into six equal parts, accurately set out and marked with a center punch; and as there was a possibility of the bar breaking outside either of the two end marks, a length equal to one of the divisions was marked beyond them.

The wrought iron test bars were cut from flat bars made from faggoted scrap, and manufactured by the Hull Forge Company.

The malleable cast iron test bars were cast by Messrs. Andrew Handyside and Company, Derby, from a pattern made to the required shape, the width in the center being $\frac{1}{8}$ inch larger than the finished size, to enable them to be all shaped exactly to the section, after which they were set out and marked as before. The net sectional area of the bars was 0.75 inch.

The steel bars for the tensile tests were of Bessemer steel, manufactured by Messrs. Brown, Bailey and Dixon, the test strips being cut from a bar $4\frac{1}{2}$ inches wide by $\frac{5}{8}$ inch thick, shaped and set out as before, the net sectional area being 0.62 inch.

The results of the experiments with tensile strains are shown in Tables I., II. and III., in which are recorded the breaking strain per square inch of the original section, the percentage of extension, and the reduction of area at the fracture. The extension of the bars between the several points marked in their length is shown on Plates 8 and 9, where the thick horizontal lines, from the center of each of the six divisions, represent the percentage of extension of the bars at those points, and can be read off by the vertical lines, which are drawn to a scale of $\frac{1}{8}$ inch to 1 per cent. The total percentage of extension is given at the bottom of each diagram, underneath which is shown the original section of the bar, with the reduced section inside, shaded to show also the nature of the iron at the fracture. The malleable iron castings are not represented by similar diagrams, for the total extension of the bar is so very small that the amount between each of the six divisions would be hardly perceptible.

It is the general opinion that, when a bar is tested, the extension along its length is uniform, except at that portion where the fracture takes place; that is to say, all the horizontal lines, except the one at fracture, would be equal. The result of these experiments, however, shows that such is not the case, the irregularities, in some instances, especially those for wrought iron, being conspicuous. This is important, as it raises the question of the value of the reduction of area as a measure of the ductility of the material; for it is possible to have a reduction of area, with a large permanent extension, the latter condition being, in the author's opinion, the best

* It would be far better, and would simplify matters considerably, if engineers would adopt some standard length from which to measure the amount of extension. Comparisons of results of different experiments could then be correctly made, whereas, at present, the specified extension of any material is an ambiguous quantity, depending upon the length adopted, which, in many published tables of results, and in many specifications, is never mentioned.—J. J. W.

indication of the qualtity of ductility. The breaking strain is also occasionally expressed in terms of the reduced area of the fracture; but this can hardly be of much value, for the extension or reduction of area and the breaking strain represent two distinct qualities of the material, and one cannot be well expressed in terms of the other. Of two bars, one bar might possibly have a high breaking strain with a small reduction of area, and the other a low breaking strain with a proportionally large reduction of area; and if the above plan were adopted, the results obtained would have the same numerical value. Again, it is possible, and probable, in a bar of very ductile material, that before it actually breaks the strain is reduced; that is to say, the real strain required at last to part the bars is less than that applied before the ultimate extension takes place; and as this strain cannot be easily measured, owing to the suddenness of the change, it shows clearly that the breaking weight recorded is the amount required to fracture the bar of a certain original section; and should this amount be expressed in terms of the fractured area no real value can be attached to it.

EXPERIMENTS ON CAST IRON BARS SUBJECTED TO TRANSVERSE STRAINS.

Owing to almost the impossibility of breaking bars of wrought iron or steel with a transverse strain, on account of the great deflection which takes place before fracture, these experiments were limited to sample bars of cast iron. Twelve bars were experimented upon, six at 50°, and six at 5° Fahrenheit. Each bar was 3 feet 6 inches long, by 2 inches deep, 1 inch wide, and rested on its edge on supports 3 feet apart, in the crosshead shown in Figs. 2 and 3. When the bars were tested at the lower temperature they were covered with snow for three days, and for three hours previous to the test with the freezing mixture, with which they were also covered during the test, in a long trough fitting up to the crosshead, the front being hinged to enable the bar to be withdrawn, and another inserted. The results of these experiments are recorded in Table IV., where the breaking strain of each bar is given in cwts., and the deflection before fracture in inches.

EXPERIMENTS ON BARS SUBJECTED TO IMPACT.

The materials used in these experiments were wrought iron, best tool steel, cast iron, and malleable cast iron; twelve bars of each material being tested, six of each at 50°, and 6 of each at 5° Fahrenheit. Those tested at the lower temperature were under exactly similar conditions to those which were subjected to tensile and transverse strains, as already described.

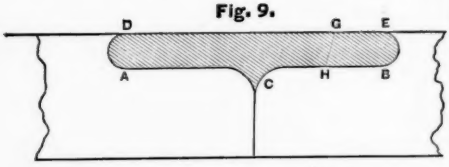
In testing the wrought iron bars, the same difficulty was experienced with the great deflection as occurred when transverse strains were applied. Bars 1½ inch square, resting on supports 18 inches apart, could not be broken with a falling weight of 40 lbs., but were doubled up to an angle less than a right angle, and still showed no signs of fracture. Bars 1 inch square, resting on supports 9 inches apart, were then tried, with similar results; and it was not until iron was adopted of a smaller section, of a common quality, and with reduced bearings, that satisfactory results could be obtained. The twelve bars finally tested were of common iron, ⅞ inch square, resting on supports 6 inches apart. The results of these experiments are recorded in Table VI., where the height of fall of a 40-lb. weight and the permanent deflection at each successive blow are given. The height from which the weight fell when the bar broke is not given, for in most cases, although this height was above the last recorded one, a fall of a few feet only would have sufficed to break the bar, and it may be fairly assumed that it was the previous blow which destroyed it.

The steel bars tested by impact were of best cast tool steel, 1 inch square, and were placed upon supports 18 inches apart. The samples were all cut from two bars rolled at the same time, and although it might be supposed that they were practically alike, the wide range of the results is very marked, the height of fall varying from 6 feet to 15 feet. The fracture of these bars was most curious, for in every instance, both at the ordinary temperature and at the lower temperature, it took the form shown in Fig. 9, the shaded portion coming away from the top side, and flying a considerable distance. These pieces were not always of the same size, and occasionally were

broken across the part shown by the dotted line at G H, but they were all of the same shape, and possessed the same peculiarities. The ends at D and E were rounded, both as shown in elevation in Fig. 9, and in plan in Fig. 10, the ends of the bar being concave to correspond, and the loose piece then finished off with a sharp knife edge at C.

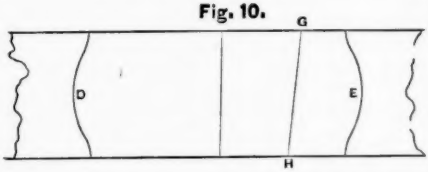
The under side of this piece, at the points A and B, was quite smooth, as if

Fig. 9.



there had been friction, and the probability is that, under the succession of blows delivered on the top of bar, it was drawn out, and as the portion of the bar above its neutral axis was in compression from the deflection, one portion was made to slide over the other, and thus the smooth surfaces at A and B were formed, the curves D A C, or E B C, evidently representing the neutral line of the two opposite forces. The bars at the lower temperature were prepared and tested under exactly the same condi-

Fig. 10.



tions as those previously described. The results of these experiments are recorded in Table VII., where the height of fall and permanent deflection at each blow are given.

The malleable cast iron bars tested by impact were 3 feet 6 inches long, by $1\frac{1}{2}$ inch deep, by 1 inch wide, and were originally intended to have been broken with a transverse strain; but the deflection was again found to be so great that it was impossible to do so with the machine, the stroke of the piston not being long enough. The bars were placed upon supports 1 foot 6 inches apart, and were tested in the same manner, and under the same conditions as the other bars, six being at 50°, and six at 5° Fahrenheit. The falling weight was 40 lbs. The results of these experiments are recorded in Table VIII.

The ordinary cast iron bars tested by impact were 10 inches long, by 2 inches deep, by 1 inch wide, and rested on their edges upon supports 6 inches apart; the falling weight being 10 lbs. only, instead of 40 lbs., as in all the other experiments. The same number of bars was tested as before, and under similar conditions, the results being recorded in Table V.

SUMMARY OF RESULTS.

A summary is given in Table IX., where the average of each set of experiments is tabulated.

Upon examination, the results obtained by submitting the bars of wrought iron and Bessemer steel to a tensile strain will be found to a great extent to agree with those by M. Styffe. The figures show clearly that severe cold does not affect the tensile strengh of the materials, but that it increases the ductility of each of them.

When, however, cast iron bars are submitted to a transverse strain, the results show that both their strength and flexibility are considerably affected by the action of severe cold; and when all the four metals, wrought iron, cast iron, steel and malleable cast iron, are subjected to the force of impact, the same result is observed in each, viz., that at a low temperature it requires either a lower fall or a less weight to break them, and their flexibility is considerably diminished. This result is the one anticipated by Mr. Sandberg, and, although his opinion is to some extent confirmed by the present experiments, the differences observed in his experiments were far greater, perhaps, for the reasons already explained.

The results of the experiments may be summed up as follows, viz.:

1. When bars of wrought iron or of steel are submitted to a tensile strain and broken, their strength is not affected by severe cold (5° Fahrenheit), but their ductilty is increased about 1 per cent. in iron and 3 per cent. in steel.*

* As far as can be judged from the small number of malleable cast iron bars which fairly broke when at the low temperature, it would appear that the tensile

2. When bars are submitted to a transverse strain at a low temperature, their strength is diminished about 3 per cent. and their flexibility about 16 per cent.

3. When bars of wrought iron, malleable cast iron, steel and ordinary cast iron, are subjected to a force of impact at a temperature of 5° Fahrenheit, the force required to break them, and the extent of their flexibility, are reduced as follows, viz.:

	Reduction of force of Impact. Per cent.	Reduction of Flexibility. Per cent.
Wrought iron.....	about 3	about 18
Steel (finest cast tool).	" 1	" 17
Malleable cast iron...	" 4½	" 15
Cast iron.....	" 21	not taken.

It will be noticed from the Tables that, when the malleable iron castings were tested with a tensile strain at the low temperature, four out of the six bars broke through the eye. This unfortunately interfered with a fair average being taken, but on the other hand, it strengthens the opinion that the material is influenced by the action of severe cold, for the sectional area of the bars through the eye was nearly twice that of the center, and as in most cases the metal was perfectly clean at the fracture, the bar was evidently not broken by a direct tensile strain, but by some indirect action.

It is difficult to reconcile the results of the experiments on impact with those with a tensile strain; one appears to contradict the other. It must, however, be remembered that the conditions under which the bars were broken at the low temperature were not identical in the two cases. When the bars were being broken by impact, it may be fairly assumed, that their temperature was constant; but when they were broken by a tensile strain, it certainly was not so, for on approaching the breaking point the temperature of the bars near the point of rupture increased considerably; instead of being at 5° Fahrenheit as at the commencement, it was much higher, notwithstanding the action of the freezing mixture. This rise of temperature is very sudden, and would probably only affect the ultimate breaking strain, and not the extension, which most likely would have taken place before the rise commenced; yet it is hard to conceive why the material should extend more in the cold, unless it be that the evident contraction or altered position of the particles tends in some way to increase its facility for being drawn.

The question now arises, which of the results is to be taken as indicating the real condition of iron and steel at the low temperature, those obtained from the experiments with tensile strains, or those obtained from the experiments by impact? As both materials, when manufactured into rails, tires, axles, chains, &c., are, when in use, continually subjected to sudden shocks or blows, and as there appears to be a doubt about the correctness of the results obtained by tensile strains on account of the great heat evolved before fracture raising the temperature of the bars above freezing point, the author is of opinion that the conditions under which the tests with the falling weight were made approached nearest to those of the material when in use; and the results so obtained, should fairly represent the structural condition of the material when tested.

Although these results show that both wrought iron and steel are influenced by severe frosts, the reduction of their strength and ductility is so small, that in designing any new structures or machines it may be safely neglected. Great care should, however, be taken to prevent them from being subjected to more shocks and blows than necessary, and the examination of rolling stock and permanent way should be made frequently during frosty weather.

The results obtained with cast iron bars show the state of affairs to be much more serious, and consequently every precaution should be taken to protect all cast iron work subjected to transverse strains, as in girders, long columns, gearing, &c., from the action of frost; and should this be not practicable, the working loads ought to be reduced at least 25 per cent., notwithstanding the large factor of safety generally adopted in the original design.

strength of the material is not influenced by the action of severe frost, but that its ductility is decreased.—J. J. W.

APPENDIX.

TABLE I.—EFFECTS OF TEMPERATURE ON THE TENSILE STRENGTH OF WROUGHT IRON.

Number of Test.	Description of Material.	Makers' Name.	Original Sectional Area of Test Strip.	Temperature. Fahrenheit.	Breaking Weight per sq in. of original Section.	Area of Strip at Fracture.	Reduction of Area.	Permanent Extension in a Length of 6¼ ins.	Remarks.
	Ins. In.		Sq. in.	°	Tons.	Sq. In.	Per cent.	Per cent.	
1	Flat bar iron, 4½ × ½	Hull Forge Co.	0.75	5	24.80	0.60	20.0	22.8	
2	" "	"	0.75	5	24.57	0.61	18.8	22.0	
3	" "	"	0.75	5	24.29	0.59	21.7	14.7	
4	" 6 × ½	"	0 75	5	23.38	0.56	25.6	20.8	
5	" "	"	0.75	5	25.37	0.60	20.0	21.0	
6	" "	"	0.75	5	22.18	0.60	20.0	12.6	
	Average.....		0.75	5	24.09	0.59	21.7	19.8	
7	Flat bar iron, 4½ × ½	Hull Forge Co.	0.75	50	25.00	0.56	25.6	20.2	
8	" "	"	0.75	5	22.76	0.66	12 0	11.8	Broke through neck—not included in average.
9	" "	"	0.75	5	23.68	0.65	13.3	16.1	
10	" 6 × ½	"	0.75	5	24.73	0.63	16.1	19.1	
11	" "	"	0.75	5	25.00	0.63	16.1	18.6	
12	" "	"	0.75	5	24.38	0.62	17.5	19.8	
	Average.....		0.75	50	24.26	0.62	17.5	18.7	

TABLE II.—EFFECTS OF TEMPERATURE ON THE TENSILE STRENGTH OF STEEL.

Number of Test.	Description of Material.	Makers' Name.	Original Sectional Area of Test Strip.	Temperature. Fahrenheit.	Breaking Weight per sq. in. of original Section.	Area of Strip at Fracture.	Reduction of Area.	Total Permanent Extension.	Remarks.
	Ins. In.		Sq. In.	°	Tons.	Sq. In.	Per cent.	Per cent.	
1	Bessemer steel flat bar, $4\frac{1}{2} \times \frac{5}{8}$	Messrs. Brown, Bailey & Dixon	0.62	5	45.12	0.40	36.0	19.2	The bars contracted more in center than at the edges.
2	" "	"	0.62	5	45.84	0.38	38.5	20.3	
3	" "	"	0.62	5	47.61	0.42	32.2	20.1	
4	" "	"	0.62	5	45.80	0.46	25.6	20.0	
5	" "	"	0.62	5	47.60	0.46	25 6	16.5	
6	" "	"	0.62	5	45.74	0.42	32.2	17.0	
	Average.....		0.62	5	46.29	0.42	32.2	18.8	
7	Ins. In. Bessemer steel flat bar, $4\frac{1}{2} \times \frac{5}{8}$	Messrs. Brown, Bailey & Dixon	0.62	50	46.75	Not measured	...	....	Broke at neck thus—
8	" "	"	0.62	50	46.64	0.43	31.2	15.6	
9	" "	"	0.62	50	45.48	0.43	31.2	15.9	
10	"	"	0.62	50	....	....	....	....	Broke through neck—no measurements recorded.
11	" "	"	0.62	50	....	....	....	....	Broke through neck—results not included in average.
12	" "	"	0.62	50	45.66	0.40	36.0	14.9	
	Average.....	.....	0.62	50	46.13	0.42	32.2	15.4	

TABLE III.—EFFECTS OF TEMPERATURE ON THE TENSILE STRENGTH OF MALLEABLE CAST IRON.

Number of Test.	Description of Material.	Makers' Name.	Original Sectional Area of Test Strip.	Temperature. Fahrenheit.	Breaking Weight per sq. in. of original Section.	Total Permanent Extension.	Reduction of Area.	Remarks.
			Sq. in.	°	Tons.	Per cent.		
1	Test bar cast to shape	Messrs. Andrew Handyside & Co., Derby	0 75	50	24.6	2.0	The reduction was so small that it was not recorded, but in no case did it exceed 2 per cent.	
2	" "	"	0.75	50	24.0	1.0		Broke through eye—no flaw.
3	" "	"	0.75	50	24.2	2.5		
4	" "	"	0.75	50	17.6	2.1		
5	" "	"	0.75	50	23.5	1.7		
6	" "	"	0.75	50	25.2	1.5		Broke through eye—flaw in casting.
	Average of bars 1, 3, 4 and 5.....		....	50	22.4	2.1		
7	Test bar cast to shape	Messrs. Andrew Handyside & Co., Derby	0.75	5	23.0	2.0		
8	" "	"	0.75	5	....	...		Broke through eye—flaw in casting.
9	" "	"	0.75	5	....	...		Broke through eye—no flaw.
10	" "	"	0.75	5	21.5	1.0		" " "
11	" "	"	0.75	5	....	...		" " "
12	" "	"	0.75	5	....	...		
	Average of bars 7 and 10.....		....	5	22.2	1.5		

TABLE IV.—EFFECTS OF TEMPERATURE ON THE TRANSVERSE STRENGTH OF CAST IRON.

Number of Test.	Section of Test Bar.	Distance between Points of Support.	Breaking Weight.	Deflection before Fracture.	Temperature. Fahrenheit.
	Ins. In.	Feet.	Cwt.	Inch.	°
1	2 × 1	3	27.8	0.29	50
2	"	"	29.0	0.30	"
3	"	"	29.4	0.31	"
4	"	"	30.4	0.35	"
5	"	"	27.4	0.29	"
6	"	"	27.8	0.34	"
	Average.....		28.6	0.31	
7	2 × 1	3	26.4	0.23	5
8	"	"	23.4	0.24	"
9	"	"	Not broken.	..	"
10	"	"	29.4	0.27	"
11	"	"	31.8	0.31	"
12	"	"	28.4	0.29	"
	Average.....		27.8	0.26	

NOTE.—Owing to an irregularity in the casting, bar No. 9 would not enter the testing machine and was not broken.

TABLE V.—EFFECTS OF TEMPERATURE ON CAST-IRON BARS WHEN SUBJECTED TO IMPACT.

Weight of monkey, 10 lbs.

Number of Test.	Length of Bar.	Section of Bar.	Distance between Points of Support.	Height of Fall required to Break the Bar.	Temperature. Fahrenheit.
	Inches.	Ins. In.	Inches.	Ft. Ins.	°
1	10	2 × 1	6	3 9	5
2	"	"	"	3 7	"
3	"	"	"	3 5	"
4	"	"	"	3 10	"
5	"	"	"	4 4	"
6	"	"	"	3 8	"
	Average.....			3 9	
7	10	2 × 1	6	5 0	50
8	"	"	"	4 8	"
9	"	"	"	4 9	"
10	"	"	"	4 11	"
11	"	"	"	4 9	"
12	"	"	"	4 7	"
	Average.....			4 9½	

TABLE VI.—EFFECTS OF TEMPERATURE ON WROUGHT-IRON BARS WHEN SUBJECTED TO IMPACT.

Length of test bars.....18 inches. Distance between points of support..... 6 inches.
Section of " ..... $\frac{7}{8}$ inch square. Weight of monkey..... .....40 lbs.

	Temperature 50° Fahrenheit.												Temperature 5° Fahrenheit.											
No. of Test	1		2		3		4		5		6		7		8		9		10		11		12	
No. of Blow.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.
	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.
1	4 0	0.20	3 0	0.08	3 0	0.12	4 0	0.14	4 0	0.16	4 0	0.22	6 0	0.28	5 0	0.52	4 0	0.10	3 0	0.08	3 0	0.24	3 0	0.06
2	4 6	0.28	3 6	0.20	3 6	0.24	4 6	0.32	4 6	0.36	4 6	0.34	7 0	0.52	+	b'ke	4 6	0.38	3 6	0.18	3 6	0.28	3 6	0.18
3	+	b'ke	4 0	0.32	4 0	0.34	5 0	0.52	5 0	0.50	5 0	0.44	+	b'ke	..	..	+	b'ke	4 0	0.34	4 0	0.48	4 0	0.32
4	..	..	4 6	0.42	4 6	0.50	+	br'ke	5 6	0.64	5 6	0.64	..	..	..	..	..	..	4 6	0.44	4 6	0.54	4 6	0.48
5	..	..	5 0	0.56	5 0	0.60	..	..	6 0	0.84	+	br'ke	..	..	..	..	..	..	+	br'ke	5 0	0.70	5 0	0.64
6	..	..	5 6	0.76	5 6	0.84	..	..	6 6	1.10	..	..	..	..	..	..	..	..	..	..	+	br'ke	5 6	0.80
7	..	..	+	b'ke	6 0	0.98	..	..	+	br'ke	..	..	..	..	..	..	..	..	..	..	..	..	6 0	0 92
8	..	..	..	..	+	b'ke	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	+	br'ke

Average ultimate fall.....5 feet 6 inches.
" " deflection ....0.71 inch.

Average ultimate fall.....5 feet 4 inches.
" " deflection.....0.58 inch.

TABLE VII.—EFFECTS OF TEMPERATURE ON STEEL BARS WHEN SUBJECTED TO IMPACT.

Length of test bars.....18 inches. Distance between points of support.....6 inches.
Section of " ..... 1 inch square. Weight of monkey.....40 lbs.

Temperature 50° Fahrenheit.

No. of Blow.	No. of Test 1		2		3		4		5		6	
	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.
	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.
1	1 0	0.04	1 0	0.02	2 0	0.00	4 0	0.02	4 0	0.18	2 0	0.00
2	1 6	0.05	1 6	0.06	3 0	0.01	4 6	0.04	5 0	0.22	3 0	0.08
3	2 0	0.06	2 0	0.08	4 0	0.08	5 0	0.05	6 6	0.42	4 0	0.14
4	2 6	0.08	2 6	0.12	5 0	0.12	5 6	0.10	7 6	0.62	5 0	0.16
5	3 0	0.14	3 0	0.18	+	b'ke	6 0	0.22	8 0	0.68	6 0	0.18
6	3 6	0.16	3 6	0.20	..	..	6 6	0.24	9 0	0.84	+	br'ke
7	4 0	0.18	4 0	0.22	..	..	7 0	0.34	10 0	0.98	..	..
8	4 6	0.20	4 6	0.26	..	..	7 6	0.36	11 0	1.20	..	..
9	5 0	0.25	5 0	0.30	..	..	8 0	0.48	12 0	1.34	..	..
10	+	b'ke	5 6	0.34	..	..	8 6	0.62	13 0	1.56	..	..
11	..	..	6 0	0.40	..	..	9 0	0.72	14 0	1 60	..	..
12	..	..	6 6	0.46	..	..	9 6	0.80	+	br'ke	..	..
13	..	..	7 0	b'ke	..	..	+	br'ke	..	..	..	..

Average ultimate fall.....7 feet 9 inches.
" " deflection.....0.59 inch.

Temperature 5° Fahrenheit.

No. of Blow.	No. of Test 7		8		9		10		11		12	
	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.
	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.
1	1 0	0.00	3 0	0.01	2 0	0.00	4 0	0.02	3 0	0.01	3 0	0.01
2	2 0	0.01	3 6	0 02	2 6	0.01	5 0	0.10	4 0	0.02	4 0	0.08
3	3 0	0.02	4 0	0.08	3 0	0.04	6 0	0.28	4 6	0.06	5 0	0.16
4	3 6	0.04	4 6	0.12	3 6	0.06	7 0	0.38	5 0	0.10	5 6	0.26
5	4 0	0.06	+	b'ke	4 0	0.10	8 0	0.52	5 6	0.14	6 0	0.30
6	4 6	0.10	..	..	4 6	0.12	9 0	0.62	6 0	0.16	6 6	0 42
7	5 0	0.14	..	..	5 0	0.20	10 0	0.78	6 6	0 20	7 0	0.46
8	5 6	0 20	..	..	5 6	0.24	11 0	0.88	+	br'ke	7 6	0.50
9	6 0	0.28	..	..	6 0	0.30	12 0	1.02	..	..	8 0	0.64
10	6 6	0.34	..	..	6 6	0.40	12 6	1.04	..	..	8 6	0.72
11	+	b'ke	..	..	+	b'ke	13 0	1.10	..	..	+	br'ke
12	..	..	..	..	..	..	13 6	1.18				
13	..	..	..	..	..	..	+	br'ke				

Average ultimate fall.....7 feet 8 inches.
" " deflection.....0.49 inch.

TABLE VIII.—EFFECTS OF TEMPERATURE ON MALLEABLE CAST IRON BARS WHEN SUBJECTED TO IMPACT

Length of test bars..... ...3 feet 6 inches.
Section of " .....1½ inch × ½ inch.
Distance between points of support.....18 inches.
Weight of monkey. .....40 lbs.

	Temperature 50° Fahrenheit.												Temperature 5° Fahrenheit.											
No. of Test	1		2		3		4		5		6		7		8		9		10		11		12	
No. of Blow.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.
	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins.	in.	ft. ins	in.
1	1 0	0.08	3 0	0.12	4 0	0.26	4 0	0.22	4 0	0.16	4 0	0.14	4 0	0.14	4 0	0.20	4 0	0.20	4 0	0.14	4 0	0.12	4 0	0.18
2	2 0	0.12	4 0	0.24	5 0	0.32	5 0	0.30	5 0	0.30	5 0	0.42	5 0	0.24	5 0	0.30	5 0	0.40	5 0	0.16	5 0	0.32	5 0	0.38
3	3 0	0.26	5 0	0.42	6 0	0 48	6 0	0.44	6 0	0.44	+	br'ke	6 0	0.50	6 0	0.50	6 0	0.54	6 0	0.36	6 0	0.54	+	br'ke
4	4 0	0.38	6 0	0.60	7 0	0.64	7 0	0.62	7 0	0.56	..	..	7 0	0.64	7 0	0.62	7 0	0.68	7 0	0.40	7 0	0.64	..	..
5	5 0	0.50	7 0	0.76	8 0	0.82	7 6	0.70	8 0	0.72	..	..	7 6	0.78	7 6	0.81	7 6	0.82	7 6	0.50	8 0	0 68	..	..
6	6 0	0.82	8 0	0.90	+	b'ke	8 0	0.84	8 6	0.86	..	..	8 0	0.82	+	b'ke	+	b'ke	8 0	0.60	8 6	0.92	..	..
7	7 0	0 96	+	b'ke	..	..	8 6	0.98	9 0	0.96	..	..	+	b'ke	..	..	..	..	8 6	0.66	+	br'ke	..	..
8	8 0	1.04	..	..	..	..	+	br'ke	+	br'ke	..	..	..	..	..	..	..	..	9 0	0 76				
9	9 0	1.18	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	+	br'ke				
10	+	b'ke																						

Average ultimate fall.....7 feet 11 inches.
" deflection.....0.88 inch.

Average ultimate fall.....7 feet 7 inc es.
" deflection.....0.75 inch.

TABLE IX.—SUMMARY OF RESULTS.

TENSILE STRAINS. (For details see Tables I., II., and III.)

Description of Material.	Sectional Area of Test Bar.	Average Breaking Weight per Square Inch.	Average Permanent Extension in Length of 6¼ inches.	Average Reduction of Area.	Temperature. Fahrenheit.
	inches. inch.	sq. inch.	Tons.	per cwt.	per cent.	°
Wrought-iron flat bars	{ 6 × ¼ } { 4½ × ½ }	0.75	24.09	19.8	21.7	5
" " "		0.75	24.26	18.7	17.5	50
Bessemer steel "	4½ × ⅝.	0.62	46.29	18.8	32.2	5
" " "		0.62	46.13	15.4	32.2	50
Malleable cast iron		0.75	22.20	1.5	..	5
" "		0.75	22.40	2.1	..	50

TRANSVERSE STRAINS. (For details see Table IV.)

Description of Material.	Sectional Area of Test Bar.	Distance between Points of Support.	Average Breaking Weight per Square Inch.	Average Deflection before Fracture.	Temperature. Fahrenheit.
Ft. Ins. Ft. In.	sq. inches.	feet.	cwt.	inch.	°
Cast-iron bars, 3 6 × 2 × 1.	2	3	27.8	0.26	5
" " " "	2	3	28.6	0.31	50

IMPACT. (For details see Tables V., VI., VII., and VIII.)

Description of Material.	Section of Test Bar.	Distance between Points of Support.	Average Height of Fall.	Average Permanent Deflection.	Temperature. Fahrenheit.
	sq. inches.	inches.	feet ins.	inch.	°
Wrought-iron bars.....	⅞	6	5 4	0.58	5
" "	⅞	6	5 6	0.71	50
Best cast tool steel bars.....	1	18	7 8	0.49	5
" "	1	18	7 9	0.59	50
Malleable cast-iron bars.....	1¼ × ¾	18	7 7	0.75	5
" "	1¼ × ¾	18	7 11	0.88	50
Cast-iron bars.....	2 × 1	6	3 9	{ Not per- } { ceptible. }	5
"	2 × 1	6	4 9⅛		50

TABLE X.—CHEMICAL ANALYSES OF THE MATERIALS USED IN THE EXPERIMENTS.*

Materials.	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Graphite	Iron (by Difference).	Total.
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
Bessemer steel.....	0.400	0.079	0.107	0.044	1.001	....	98.369	100.000
Cast tool steel.....	1.145	0.121	0.042	0.013	0.197	....	98.482	100.000
Best bar iron.....	0.060	0.158	0.073	0 256	trace.	....	99.453	100.000
Malleable cast iron.. .	2.085	0.499	0.446	0 021	0.183	....	96.766	100.000
Ordinary cast iron....	0.300	1.618	0.119	1.107	0.563	2.643	93.650	100.000
Common bar iron	0.067	0.136	0.036	0.347	0.016	....	99.398	100.000

* These analyses were made by Mr. Edward Richards, F. I. C., Chemist to the Barrow Hæmatite Steel Company, Limited.

THE ARCHÆOLOGY OF THE CUMBERLAND IRON TRADE.

From "The Architect."

A paper on "The History of Iron Manufacture in West Cumberland" was read by Mr. H. A. Fletcher, at the meeting of the Cumberland and Westmoreland Archæological Society.

Mr. Fletcher said, that, although the different modes of iron-making known to successive ages from the Roman bloomery, from which a small portion of malleable iron was extracted from the richer ores in a tiny furnace urged by the natural force of the wind, followed afterward by a slightly improved furnace, worked by hand bellows, and a little later by the force of bloomsmithy, with bellows or other blowing machinery driven by water-power, as well as the smelting of pig iron in blast furnaces, first with charcoal as fuel and then with pit coal, or rather coke, together with the making of wrought iron from the pig in the open hearth, until superseded by the invention of the art of puddling by Henry Cort, have all been practiced in West Cumberland, it had only been after long intervals and on small scales, and it was only within our own time that this division of the county had become a great iron producing center. The rich red hematite iron ore of Cumberland could not escape the watchful eyes of its Roman occupiers; but it is a little remarkable that, so far as the writer is aware, no vestiges of the scoriæ of Roman iron bloomeries have been found in the parts where the ore is most abundant, such as Egremont, Cleator, and Frizington; but possibly cultivation of the soil may have obliterated all traces, and it is not improbable that such stray pieces of kidney ore as may have been found in other parts on the surface of the ground or in the beds of streams, and the vein-like deposits in the crevices of some of the mountain rocks, may have been sufficient for their limited make. At the foot of Wastwater Lake there was every indication of there having been a veritable bloomery. That iron making was practiced in this part in the twelfth century they had proof from the Chartulary of the Abbey of Holme Cultram. Traces of charcoal furnaces had been found in various places on excavations being made. Coming to the period when the smelting of iron in blast furnaces with coke as fuel became an established commercial success, which was not until after 1735, we find that about the middle of the eighteenth century such furnaces were built within the Cumberland coalfield, most or all of them with furnaces attached for making iron castings, at four different places—viz., Little Clifton, Maryport, Seaton, and Frizington; but little success seems to have attended them, for these works all seem to have been abandoned after but short careers, except those at Seaton. About 1750, or possibly

a little earlier, Messrs. Cookson & Co., who worked coal mines at Clifton and Greysouthen, erected a blast furnace near Little Clifton, on the banks of the river Marron, which supplied the needful water power for blowing. The site is still distinguishable, and a few cottages at a little distance for the use of the workmen retain the name of Furnace Houses. There was a foundry in connection with the works, where light castings, for the use of mill-wrights and farmers, were made, as well as those required at the proprietors' own colliery. On the neighboring roads may be found pieces of the furnace slag with which they have been repaired, and many of these are of a character which indicate a not very satisfactory result in smelting. The old furnace at Maryport was built in 1752. It was square in cross section, and appeared to have been about 36 feet high and 11 or 12 feet diameter at the "boshes," or widest part. The Seaton Ironworks, near Workington, were established in 1762. The blast furnace had been in use here, and cast and wrought iron manufactured. But little information had been gathered respecting the furnace at Howth Gill, Frizington, for, unfortunately, who could have best given it had passed away, but an inspection of the ground showed two circular excavations about 12 yards in diameter, 6 or 8 feet deep, and about 24 yards apart, which are clearly the sites of two blast furnaces of considerable size. An attempt had been made at Frizington to manufacture wrought iron direct from the ore with pit coal from 1728 to 1730. In 1799, Adam Heslop, along with his brothers Crosby and Thomas, and several other partners, under the style of Heslops, Millward, Johnson & Company, founded the Lowca Ironworks, with a view of smelting, in addition to the iron foundries which they then erected, along with appliances for making the Heslop Patent steam engines; but after laying the foundations of two blast furnaces, abandoned them. Their lease of the site from Mr. J. C. Curwen included the right of working the thin bands of clay ironstone, of the coal measures which crop out on the beach in Harrington parish, as well as some other mineral rights. This was the last attempt to establish blast furnaces in the West Cumberland coalfield, until the Whitehaven Hematite Iron Company built their works at Cleator Moor in 1841. At the Flosh, Cleator, where Mr. Ainsworth's Flax Mills now stand, there were some works for making bar iron and steel, which were abandoned and dismantled in 1799. The earliest record which has been found of iron ore mining in Cumberland seems to be the grant of the forge at Winefel to the monks of Holm Cultram Abbey in the twelfth century, which also included a mine at Egremont (by inference of iron, being in connection with a forge); and Thomas de Multon confirms a gift to the same Abbey, "de quaruor duodenis minæ ferri in Coupland." In the latter half of the seventeenth century ore was worked to a considerable extent at Langhorn, near Egremont, where there was a deposit close to the surface, excavated in the open like a stone quarry. Much of the ore raised in 1749 was shipped at Parton in small craft, carrying from 10 to 61 tons, to Chester, to be smelted in a furnace belonging to Mr. Gee, and situated either near Wrexham or in Shropshire, it is not quite clear which. The ore stored at Parton under a shed for the purpose, ready for rapid shipment, was most likely carried there on the backs of horses, for it does not seem at that time there was any direct road from Frizington passable by wheeled vehicles, Ore seems to have been worked freely at Cleator a century ago, and at Crossfield some fifty years earlier. In the Millom district, Mr. Massicks is of opinion that no part of the vast deposits at Hodbarrow were touched till about fifty years ago, when a small quantity was worked near the shore, and that the Huddlestone furnaces were partly supplied from a small vein in the limestone close by, the remainder being brought from Furness.

A VIKING'S SHIP.

From "The Architect."

THE correspondent of *The Times* in Copenhagen gives the following account of a remarkable discovery:

A recent antiquarian discovery of a most remarkable nature has put the scientific world of Scandinavia in commotion, and is attracting the general attention of the Scandinavian nations, fondly attached to their venerable history and ancient folk-lore, and full of devotion for the relics of the great past. In age this discovery cannot cope with the treasure-trove brought forth by Schliemann from Ilian or Grecian soil, nor even with the excavations conducted by German *savans* at Olympia. It only carries us back to a period distant a thousand years from our time, but still it initiates the modern time in the life and customs of bygone ages, and vivifies the cycle of old northern poems and sagas as fully as the "Iliad" is illustrated by the excavations at Hissarlik or at Mycenæ, or the Pindaric odes by those at Olympia.

In the southwestern part of Christiania Fjord, in Norway, is situate the bathing establishment of Sandefjord, renowned as a resort for rheumatic and nervous patients. The way from this place to the old town of Tönsberg conducts to a small village called Gogstad, near which is a tumulus or funereal hill, long known in the local traditions under the name of King's Hill (*Kongshaugs*). In the flat fields and meadows, stretching from the fjord to the foot of the mountains, this mole, nearly 150 feet in diameter, rises slowly from the ground, covered with green turf. A mighty king, it was told, had here found his last resting place, surrounded by his horses and hounds, and with costly treasures near his body, but for centuries superstition and the fear of avenging ghosts had prevented any examination of the supposed grave, until now the spirit of investigation has dared to penetrate into its secrets. The result has been the discovery of a complete vessel of war, a perfect Viking craft, in which the unknown chieftain had been entombed.

The sons of the peasant, on whose ground the tumulus is situate, began in January and February this year an excavation. They dug down a well from the top, and soon met with some timber. Happily they suspended their work at this point, and reported the matter to Christiania, where the "Society for the Preservation of Ancient Monuments" took up the task, and sent down Mr. Nicolaysen, an expert and learned antiquary, to conduct the further investigation. Under his able guidance the excavation was carried on in the months of April and May, and brought to a happy conclusion, revealing the whole body of an old Viking vessel, 74 feet long between stem and stern, 16 feet broad amidships, drawing 5 feet, and with twenty ribs. This is by far the largest craft found from the olden times. In 1863 the Danish Professor Engelhardt dug out from the turf-moor at Nydam, in Schlesvig, a vessel 45 feet in length, and in 1867 another was found at Tune, in Norway, 43 feet long; but neither of these can, in completeness or appointment, be compared with the craft now excavated at Gogstad. The tumulus is now nearly a mile distant from the sea, but it is evident from the nature of the alluvial soil that in olden times the waves washed its base. The vessel had consequently been drawn up immediately from the fjord, and placed upon a layer of fascines or hurdles of hazel branches and moss; the sides had then been covered with stiff clay, and the whole been filled up with earth and sand to form the funereal hill. But the craft is placed with the stem towards the sea. It was the grand imagination of the period that when the great Father of the Universe should call him, the mighty chieftain might start from the funereal hill with his fully-appointed vessel out upon the blue ocean.

In the stem of the ship, first disclosed to the eye, several interesting objects were found. A piece of timber proved to be the stock of the anchor; it was perforated to hold the iron, but of this

no more was found than a few remnants. In the bottom the remains of two or three small oaken boats of a very elegant shape were placed over a multitude of oars, some of them for the boats, others, 20 feet long, for the large craft itself. The form of these oars is highly interesting, and very nearly like those still in use in English rowing matches, ending in a small, finely-cut blade, some of them with ornamental carvings. The bottom-deals, as well preserved as if they were of yesterday, are ornamented with circular lines. Several pieces of wood had the appearance of having belonged to sledges, and some beams and deals are supposed to have formed compartments dividing the banks of the rowers on each side from a passage or corridor in the middle. In a heap of oaken chips and splinters was found an elegantly shaped hatchet, a couple of inches long, of the shape peculiar to the younger Iron Age. Some loose beams ended in roughly carved dragons' heads, painted in the same colors as the bows and sides of the vessel—to wit, yellow and black. The colors had evidently not been dissolved in water, as they still exist; but, as olive oil or other kinds of vegetable oil were unknown at the time, it is supposed that the colors have been prepared with some sort of fat, perhaps with blubber.

As the excavation proceeded, the whole length of the vessel was laid bare. All along the sides, nearly from stem to stern, and on the outside, extended a row of circular shields, placed like the scales of a fish. Nearly 100 of these are remaining, partly painted in yellow and black, but in many of them the wood had been consumed and only the central iron plate is preserved. From the famous tapestry of Bayeux it is well known that the ancient viking vessels had these rows of shields along the free-board, but it was supposed that they were those used by the warriors in the strife, and only placed there for convenience. It is now clear that they had only an ornamental purpose, being of very thin wood, not thicker than stiff pasteboard, unable to ward off any serious hit from a sword. In the middle of the vessel a large oaken block, solidly fastened to the bottom, has a sqare hole for the mast, and several contrivances show that the mast was constructed for being laid down aft. Some pieces of tow and a few shreds of woollen stuff, probably the mainsail, were found here. In this part of the vessel was built the funereal chamber, formed by strong planks and beams placed obliquely against each other, and covering a room of nearly 15 feet square. Here, just as expectations were raised to the highest pitch, a bitter disappointment awaited the explorers. Somebody had been there before them. Either in olden times, when the costly weapons of an entombed hero tempted the surviving warriors, or in some more modern period when the greediness for treasure was supreme in men's minds, the funereal hill has been desecrated, its contents pilfered and dispersed, and what has been left is only due to the haste and fear under which the grave robbers have worked. A few human bones, some shreds of a sort of brocade, several fragments of bridles, saddles, and the like in bronze, silver, and lead, and a couple of metal buttons, one of them with a remarkable representation of a cavalier with lowered lance, are all that has been got together from the heap of earth and peat filling the funereal chamber. On each side of it, however, were discovered the bones of a horse and of two or three hounds. In the forepart of the ship was found a large copper vessel, supposed to be the kitchen caldron of the equipage, hammered out of a sole piece of copper, and giving a most favorable proof of that remote period's handicraft. Another iron vessel with handles, and with the chain for hanging it over the fire, lay close to a number of small wooden drinking cups. The detailed account of all these objects would claim too much space.

It was originally the intention to dig out the whole craft from the hill, and transport it to the Museum at Christiania. A large proprietor of the neighborhood, Mr. Treschow, offered to pay the expense. But on closer examination, and after consultation with one of the constructors of the navy, it was considered unsafe to attempt such a dislocation. It is now the intention to leave the craft where it was found, and to protect it against the influence of the weather by building a roof over the hill, only carrying to the Museum at Chris-

tiania the smaller objects. The Government has at once consented to defray the expenses necessary for the purpose.

As to the time when the tumulus was thrown up, there is no doubt among the antiquarians that it dates from the period termed the "younger Iron Age," distant from our day nearly a thousand years or a little more. We shall have to carry our thoughts back to about the year 800, when Charlemagne was crowned Emporer at Rome, but when Norway was still divided between the wild chieftains and sea-kings, vanquished towards the close of the ninth century by the great Harold, the Fair-haired, founder of the Norwegian state and nation.

THE STRENGTH OF RAILWAY BRIDGES.

From "The Engineer."

On the night of Thursday, the 17th inst., a very alarming accident occurred on the Hereford, Hay and Brecon Railway, a branch line worked by the Midland Company. A bridge of three arches, which carries the line across the river Wye at a point between Hay and Brecon, gave way, and a goods train fell into the river. The unfortunate engine-driver was killed on the spot, and the stoker was terribly injured. It is not yet quite certain either why or when the bridge fell. A very heavy train of twenty-four carriages filled with passengers had passed over it a few hours before. The river was in flood, and it is supposed that the foundations of the bridge were undermined and carried away; and that the bridge, possibly, had fallen before the goods train reached it. On these points, information, now lacking, will, of course, be forthcoming in due time. Meanwhile, we have presented for our consideration the broad fact that a railway bridge has fallen; that a goods train has gone into a river with a great destruction of property and the loss of life, and that a passenger train might just as well have gone in as a goods train, in which case, probably, two or three hundred lives would have been lost instead of one. The circumstances of the accident are in no wise unique. A trumpery little bridge near Beckenham broke down because of a flood some years ago, and many lives were lost. The Ashtubula accident in America is no doubt fresh in the minds of many of our readers. The Tay Bridge we need hardly name. Last year two bridges, one at Llandulas and the other at Aber in North Wales, were washed away, so to speak, and nothing but apparently excessive vigilance avoided one frightful calamity or two; and we think we are justified now in asking whether railway companies and their engineers attach sufficient importance to some points connected with bridges, and whether a great many bridges might not be found all over the country which are really unsafe.

There are in Great Britain thousands of little railway bridges, varying in span between 20 feet and 80 feet, which were put up many years ago, and which have received scant attention since; not a few of these bridges must now be in a more or less dangerous condition. It is not difficult to prove this statement. By the Board of Trade rules, wrought iron must not be strained to more than five tons per square inch in a girder, and cast iron should not have much over 1 ton per inch put on it. Now there are railway bridges in this country which have been standing for over thirty years; some of these are nearly half a century old. Let us confine our attention to the more recent bridges. These were put up at a time when the greatest weight of an engine and tender together did not much, if at all, exceed 40 tons. Twenty-five tons for an engine and 15 tons for a tender were abnormal weights rather than the reverse. Bridges of less than 60 feet span would take such an engine and tender upon them, and this weight of 40 tons, or thereabouts, represented the maximum strain which they had to bear, and for which they were calculated. But, as time went on, heavier and heavier engines were built, and there are express engines and tenders on the

Midland Railway, for example, now, which weigh together as much as 72 tons, and these will stand on a 60 ft. bridge. If we assume that the live load on such bridges amounted to 3 tons on the inch —the dead load being 2 tons—with 40 ton engines and tenders, then with 72 ton loads the strain will not be 5 tons, but 7.4 tons, which is perhaps not a safe load. Again, there are certain little bridges—the fall of any one of which would wreck a train—which, at the most, would not take in more than two pairs of wheels of an engine. The greatest weight they would have to bear thirty-five years ago would have been about 18 tons; now it will reach 25 to 28 tons. If the original strains due to the live load on the girders, mostly cast iron, was 10 cwt. per inch, it must now be 15.5 cwt., and like reasoning applies to abutments, and piers, and foundations. Not long since we had occasion to examine several small under bridges on a main line of railway. None of them was more than about 20 feet span. In every case we found the brickwork of the abutments shaken, and the landings on which the girders rested cracked. There was no immediate danger that such bridges would give way, but there was certainly no security that they would not. We have every reason to think that our large bridges are all safe, and the fall of the Tay Bridge will make them safer than ever, because they will be more carefully looked after. For example, it is stated that one eminent consulting engineer has ordered no less than 1000 tons of iron for wind ties and other devices for strengthening bridges, since the Tay Bridge fell. The true danger lies in the small under bridges, and it has been brought about by the age of the bridges and the augmented loads which they have to carry.

The danger is by no means confined to the girders. We could point out a bridge now, not ten miles from London, which has a span of about 18 feet. It consists of four cast iron girders resting on brick abutments. This bridge became shaky in the brickwork some years ago. It would have been desperately inconvenient to stop the traffic to rebuild it, and it was quite clear that settlement of the foundations was the cause of the trouble. The road which it spans is never used, so the bridge was propped with timbers extending across between the faces of the abutments and keeping them apart. It has been so propped now for a long time; but by and by this bridge will become very unsafe, if it is not unsafe now. All over the country may be found small bridges with the brickwork or stonework of the abutment faces shaken and split; arches may be seen split right through. We could cite one case where a viaduct is split from one end to the other. It has been tied together with transverse iron rods, but it is exceedingly doubtful if this viaduct is fit to be run over at high speeds by heavy trains. Every now and then we hear of a bridge tumbling down, as for example that at Llandulas, or that over the Wye, and it is urged that the fall was quite unexpected, and that the flood must have been abnormal or it would not have gone; the truth being all the time that there was nothing abnormal about the flood, but that a process of deterioration by wear and tear had begun from the first, and that this was immensely accelerated by doubling the strains, or nearly doubling them, for which the bridge was designed. The floods every winter did a little harm, and, at last, floods, vibration, and undue strains, all acting together to the same end, brought down the bridge. If its fall was not anticipated, that was because the engineers in charge did not realize the nature of the conditions under which it was worked. We do not mean to assert that floods may not arise which baffle all calculation, and carry away bridges like reeds; but such things are very rare, and when one flood carries away a railway bridge, it may be taken for granted that other floods had previously run past it and did it some injury by scouring the foundation or otherwise.

When Capt. Tyler inspected the Bristol and Exeter Railway a few years before it was handed over to the Great Western Company, he discovered and made out a list of 20,000 defects, each defect more or less dangerous. For the most part they were in the permanent way. On our best lines the permanent way is kept in very admirable condition, and it would be difficult in 100 miles of

such roads as the Great Western, Midland, or London and Northwestern to find a dozen serious defects. Is it quite certain that as much may be said of the bridges which carry this excellent permanent way? Some years ago we saw an iron bridge taken down and replaced by one of greater strength. When the removed bridge came to be taken to pieces, it told a story "enough," as an engineer present said, to "make one's flesh creep." Cracks and corrosion spoke volumes. It is the practice now to have bridges of all kinds examined almost daily; and we believe that on most lines the engineer-in-chief, accompanied by assistants, makes a tour of inspection once a year, and reports accordingly to his directors. Such examinations may have averted many accidents; some they have not averted. It might cost much money to carry out a special inspection, in which ballast would be taken up, foundations laid open, rivers carefully sounded and their bottoms bored, brickwork opened out, culverts stripped, and, in a word, a thorough examination made. But this we do know, that, unless something of the kind be done, accidents will occur, and they will occur with increasing frequentcy as weights and speeds increase and age steals by degrees on the bridges. Bridges originally well made do not tumble down for nothing, but the perfunctory inspection of a milesman can hardly be regarded as guaranteeing the security of such structures.

BIG BRIDGE CONSTRUCTION.

From "The Builder."

THE rejection, by a Select Committee of the House of Commons, of the Bill for the construction of a slightly modified bridge over the Tay, affords a practical comment on the observations we have heretofore offered on the official inquiry into the causes of the disaster which befell the former structure. That two engineers, one Royal and one Civil, should have consented to carry on such an inquiry in the absence of the drawings of the bridge, and without making any such representation as to the absence of those drawings as might, at all events, have thrown the blame in the right quarter, was to us, at the time, inexplicable. We do not say that the Commissioners were bound to refuse to proceed with the inquiry in the absence of the drawings. But we did expect such an appeal to the Board of Trade in the first instance, and, failing redress, such a statement of the fact of this suppression of evidence in the report itself, as might have put the professional members of the Commission right with their own brethren. As it is, the shareholders have to pay the piper. Considering all that had been said, and all that had not been said, as to the responsibility of Colonel Hutchinson in respect of what was called the examination of the bridge on the part of the Board of Trade before opening the line over it for traffic, we do not see how Colonel Yolland could well have avoided reporting against the approval of a design which appears to have been adopted by the directors of the railway between their first and their second appearance before the committee—a design as to which the author admitted that "he had still much to verify." There is some confusion in the reports which we have read as to one point in his new design. From the evidence of Mr. Brunlees, it appeared as if brick piers on the existing foundations were proposed; but, on the other hand, it was stated by counsel that the piers were to be for a double width of line, while the bridge was to be, in the first instance, only for a single line. We fully agree with Colonel Yolland in the opinion that a single-line bridge should not be authorized. As to the question of brick or iron piers, it is a matter of design and of calculation, not to be settled offhand, or without due investigation. Still more important is the third requisition on which the Board of Trade has been advised to insist, namely, that the foundations should be entirely new. When demands of such a nature are made unexpectedly, before a committee, the pro-

moters of a bill are taken aback. It is possible that the addition of the proposed clauses would have the effect of at once doubling the cost of the bridge. At all events, this would take time to ascertain. Had the original design for the bridge been produced and discussed before the commission of inquiry, this company would have known what to expect. New demands could not have been raised at the eleventh hour; and the delay of a year, involving heavy expense, would have been saved to the company. As it is, however, the directors have only themselves to thank for an opposition which the suppression of the original plans rendered unavoidable, though it is to be regretted that it was not announced until the latest available moment.

The question of entirely new foundations is one of very great importance. Its turning up at this last moment affords a very striking proof of the penny-wisdom, which may prove to be pound-folly, of stinting the proper outlay for an important work. If the traffic which the Tay Bridge was to accommodate was worth the cost of building a bridge at all, even if a single line of way would in the first instance have been sufficient to accommodate the trains of the company, no person of prudence would have sanctioned the preparation of foundations that were insufficient to carry a double way. If the foundations had been put in for a bridge of the ordinary width, and if, above a certain height, the bridge had been in the first instance proceeded with for a single way alone, it is very possible that the overthrow would have been avoided. In any case, the contemplation that the need for a double line would arise at some future time ought never to have been omitted, nor should such a mode of obtaining foundations have been adopted as would have been certain to involve a very grave engineering difficulty whenever the case of widening came to be carried out.

It is well to give full attention to this part of the case, because it points to something nearer home than Dundee. In the various plans which have from time to time been ventilated as to the widening of London Bridge, the advocates appear to have closed their eyes to the nature of the foundations obtained by Rennie. This great engineer was compelled by the City authorities to build the noble monument in question in a spot which he considered not the fittest for the purpose. The true site of the bridge was abandoned for the sake of saving the expense of a temporary bridge. As far as the means at the command of the science of his day went, Rennie made the best of his design. But it was touch and go. In fact, it was "go" for some fourteen inches, and though the movement of the abutment was arrested, and the bridge has ever since been stable, there can be no certitude as to the anticipation how soon the steady action of the river in deepening its bed may set the bridge again on the move, and we think there is very little room to doubt that any tinkering of the superstructure would very rapidly have that effect.

All builders know how ticklish a thing it is to build a new wall as a continuation of an old one into which it is to be bonded. And if this be the case in the open air, on the side of a house, or on any line of plain surface, how is the difficulty increased if the junction has to be effected thirty feet under water, in an estuary or tidal river? This task, which we think it would probably prove impossible to accomplish on London Bridge without some mishap, is not an easy one to effect in the River Tay. But the putting in of brick foundations for a double line would require such a junction of new and of old work. We think that it may be very seriously questioned whether it would not prove safer, and ultimately cheaper, to build a new bridge *in toto*, and to remove all the piers of the old bridge, than to undertake the task of widening the piers of the latter. At all events, we hold it tolerably certain that there are no grounds for any confident expectation to the contrary. It might be possible to coffer-dam round the existing piers, to excavate and lay wider foundations, and to carry up the whole as a sound piece of workmanship; but with evidence before the committee that it may be necessary to protect the bottom of the river from scour "by means of stone," in fact, to pave or pitch the bottom of the Tay, we feel sure that the very best and most deliberate advice

ought to be secured before making any such attempt.

The actual position of the Tay Bridge is such as to point to the need of an exhaustive inquiry into the theory of bridges of large span. At the present time the width of the span into which a bridge may be divided—and we may say the same with regard to the roof of a station, or of any great area—depends pretty much upon the taste of the engineer. The question of level, in the case, at all events, of the bridge, is here one of primary importance. A balance has to be struck between the cost of pier and that of arch; between the cost of numerous piers, and that of arches or girders over wide spans. No definite relation can be laid down as normal between the two estimates of cost, because the cost of the piers differs to an extraordinary extent in different cases. Thus a span which it might be altogether extravagant to use in the case of a wide flat valley, might prove to be economical in the case of a deep ravine. If any approach to a general formula of proportion is to be obtained, it must include an expression for the height of the piers, and another expression for the anticipated costliness, in the matter of obtaining foundations.

It is instructive, as giving some measure of the progress made by the engineer during the past sixty years, to compare the dimensions of Old London Bridge, according to the survey of it made by Mr. Giles, in 1820, by order of the Committee of the Bridge Lands, with some of the latest erections of large spans, both in this country and the United States. The width of the river between the abutments of London Bridge, according to the survey quoted, was 931 ft. Of this width no less than 406 ft. 10 inches, or above 42 per cent., was occupied by the piers. But a further obstacle to the flow of the river was offered by the starlings, or pile-work protections, to prevent the piers from being under-cut by the current, which amounted to 293 ft. 5 in. This reduced the water-way, at low water, to 230 ft. 11 inches, or rather less than one-fourth of the normal width of the river. The consequence of this contraction was to produce a row of waterfalls through the arches of the bridge, in which the river fell 2 ft. 1 inch at neap tides, and 4 ft. 4 inches at springs; an extreme fall of 5 ft 7 inches having been noted during the occurrence of a highland flood, falling on a spring-tide ebb.

In contrast to this cumbrous and clumsy structure, we may cite the elaborate calculations brought by Professor Clericetti, of Milan, before the Institution of Civil Engineers, and published in vol. lx. of the Minutes of Proceedings of that Institution. The result, in two lines, is, that a girder can be constructed which would bear its own weight for a span of 900 meters, and that by the addition of inclined steel cables, fixed to towers rising 90 meters above the girders, a span of 1,500 meters might be obtained. The pull upon the cable, in this case, is taken at 20 kilogrammes for each square millimeter of cross section, or rather more than 13 tons per square inch. M. Max am Ende calculates the limiting span of a straight girder, with struts and diagonal ties, with 5 tons strain on the square inch, at 2,870 ft.; that for a straight girder, with diagonal struts and diagonal ties, at 4,000 ft. for iron, and 6,000 ft. for steel, with a strain of 7½ tons per inch. For a parabolic bowstring girder, the limiting span is given as 3,000 ft., the corresponding depth of the girder being 1,830 ft. For the parabolic fish girder, this gentleman proposes a limiting span of 4,200 ft., with a depth of 3,600 ft., in iron, and a span of 6,300 ft., with a depth of 5,400 ft., in steel. These are purely theoretical figures, and take into account simply the force of gravity.

As to most of this, however, the practical builder will be content to allow it to remain in the cloudy limbo of algebraical theory. What is more to the point is to inquire of what spans bridges have been actually constructed. We can obtain some valuable information on this subject from a paper by Thomas Curtis Clarke, M. Inst. C.E., which was read before the Institution of Civil Engineers on the 21st of May, 1878. But it is very remarkable, as illustrating how far we yet are from arriving at any normal rules, such as we before indicated as desirable, for the proportion between width of span and number of piers, that, in the 21 columns in which Mr. Clarke tabulates the information of which we

are about to cite a portion, no mention is made of the height of the platform of the bridge above the water which it crosses.

The width of span, then, which has been obtained in the case of sixteen important tubular and girder bridges, constructed of iron, up to the year 1877, are as follows:

Where built.	Span.	Engineer.
1. Susquehanna Riv.	307	Phœnix Bridge Co.
2. Ohio River	319	J. H. Linville
3. St. Lawrence River	330	Rob't Stephenson
4. Ohio (Parkersberg)	342	J. H. Linville
5. Rhine, Mayence	345	Gerber
6. Ohio (Louisville)	368	Albert Fink
7. Kentucky River.	375	C. S. Smith
8. Ohio (Louisville)	396	Albert Fink
9. Vistula (Dirschau)	397	Lentze
10. Conway, N. Wales	400	Rob't Stephenson
11. Ohio (Cincinnati)	415	J. H. Linville
12. Inn (Passau)	420	
13. Saltash	455	I. K. Brunel
14. Menai Straits	460	Rob't Stephenson
15. Lek, Holland	492	G. Van Diesen
16. Ohio (Cincinnati)	518	J. H. Linville

The figures merely indicate the width in feet of the longest span in each of the bridges cited. To these works should be added the suspension railway bridge over the Niagara river, immediately above the Falls, which was opened for traffic in March, 1855. The span of this bridge is 822 ft. 6 inches. The height of the platform, which carries three lines of rails, of the respective gauges of 3 ft. 6 inches, 4 ft. 8½ inches, and 5 ft. 6 inches, above the river, is 250 ft. Below the railway platform is suspended a second platform, for common road vehicles, The bridge is supported by four wire cables, of 10 inches diameter, each containing 3,640 wires of No. 9, B. W. G. The weight of the superstructure is 750 tons. The supporting strength of the cables is estimated at 7,000 tons. The bridge was designed and constructed by the late Mr. J. A. Roebling, the engineer in chief, who was also a manufacturer of wire ropes. The cost was about 500,000 dollars, or a little over £152 per foot of span.

Of the bridges in the table, those built by Mr. Stephenson over the Conway, in 1848, the Menai Straits, in 1850, and the St. Lawrence, in 1859, are all tubular girders, through which the trains run. The bridges numbered 2, 6, 8, have the top chords cast, the rest of the girders being of rolled iron. The girders are quandrangular, with pin connections. Numbers 1, 4, 7, 9, 12, 15 and 16, are all made of rolled iron. The Saltash Bridge, built by Mr. Brunel in 1859, crosses the river Tamar, about three miles north of Plymouth, at a place where the river narrows to about 1,100 ft. wide, and has a depth of 70 ft. It was at first proposed that this bridge should consist of seven openings, one of 250 ft. and six of 100 ft. each. But the Admiralty insisted that there should be only four spans, two of 300, and two of 200 ft. each, with straight soffits, and a clear headway of 100 ft. above high water. After a very careful and minute investigation of the bed of the river, made by 175 borings, carried on by aid of a wrought-iron cylinder 6 ft. diameter, and 85 ft. long, which was slung between two gun-brigs, and pitched at thirty-five different places on the river, Mr. Brunel decided upon adopting two main spans of 455 ft. each, supported on a masonry pier. For the construction of this pier a wrought-iron cylinder, 37 ft. in diameter and 90 ft. in length, was sunk through the mud at the bottom of the river to the solid rock. The total length of the bridge, including the adjoining land-openings, is 2,280 ft. It consists, besides the two main spans, of two openings of 93 ft., two of 83 ft. 6 inches, two 78 ft., two of 72 ft. 6 inches, and nine of 69 ft. 6 inches each. The central column, of solid masonry, 35 ft. in diameter, is 96 ft. in height from the rock foundation to above high-water mark. Upon this are placed four octagonal columns of cast iron, 10 ft. in diameter, carried up to the level of the roadway, which is 100 ft. above high-water mark. Holding-down lewis bolts were let into the solid rock on which this pier was built, with iron bars built into the masonry. A description of the center pier of this noble bridge, by Mr. R. P. Brereton, M. Inst. C.E., will be found in vol. xxi. of the Minutes of Proceedings of the Institution of Civil Engineers.

In the course of the discussion on Mr. Clarke's paper, from which we have cited the spans of sixteen large bridges, Mr. Barlow compared the efficiency and structural merit of the several designs,

according to a method proposed by Professor Rankine, which consists in ascertaining the limiting spans attainable on each system. The bridges in question may be arranged in four classes, viz: (1) quadrangular girders, with pin-connections; (2) the Saltash Bridge, which Mr. Clarke calls a lenticular girder; (3) lattice bridges; and (4) tubular bridges. Of these, the six examples of the first kind have an average limiting span of 900 ft., the several cases ranging from 852 ft. to 982 ft. Mr. Brunel's bridge, though of comparatively an early date, has a limiting span of rather more than 900 ft. In the lattice bridges, the waste of metal amounts to from 40 to 46 per cent., as compared with the former structures. In the tubular bridges it is still more; but it must be remembered that these were the first efforts to introduce iron in large spans in railway bridges.

In looking at the large amount of valuable information that may be gleaned from many of the sixty volumes of the Minutes of the Proceedings of the Institution of Civil Engineers, we are struck with the absence of any attempt to show such a comparative view of the cost of these great structures as would be of service in framing general rules for the guidance of the bridge builder.

The remarks which we have just quoted go in the right direction, but they only go a little way in that direction. Mr. Douglas Fox, in the discussion on Mr. Clarke's paper, gave the counsel to avoid large spans altogether if possible, because, if a pier could be introduced, even though the cost were the same, it would be a great advantage. We are disposed to agree with the recommendation. But what we want is, not to have it offered as an opinion, but to have the facts so clearly brought out as to allow them to speak for themselves. "The larger the span, the greater the risk in erection, and the greater the cost in maintenance." That, moreover, may be true, but again we wish for proof. Again, the fact that certain elements of strength are required to increase, not as the span, but as the square of the span, is one that needs being brought fully out—so as to show in what manner, other things being equal, the cost of one opening of 200 ft. span compares with that of two openings of 100 ft. span each—taking the girders alone; so that allowance may be made for the piers according to the height of the structure. We find no attempt to bring this before the professional world, and we feel very sure that architects, engineers, and builders will have reason for gratitude to the writer who shall put into available form the large mass of experience which has been attained on this subject.

Mr. Clarke, in his reply, made some observations which show that American engineers have given due attention to a subject on which it must be admitted that English engineers have not of late exhibited the most profound knowledge. "A bridge," said this gentleman (whose address is given as in New York), "is a complex structure. It has to bear not only the force of gravity, but the side pressure of the wind. It has been said that it was a simple matter to provide against the force of wind, but that was really the most difficult and complicated part of the problem. The most economical height possible had to be used to resist the force of gravity; but then the side pressure prevented the use of an economical height; consequently, the bridge, when it was finished, was a compromise between the results of two forces That was why the long-span bridges were comparatively not so high as those of shorter span. In spans of less than 200 ft. the proportion of height to span was 1-5th or 1-6th." When we find that this outcome of American practice was brought before the Institution of Civil Engineers in May, 1878, Mr. W. H. Barlow being in the chair, we cannot avoid referring to the opinion we felt bound to express (*ante*, p. 39) with regard to the report of Messrs. Hawkshaw, Bidder, Harrison, and Barlow, as to the adoption of 10 lbs. as side pressure on the Forth and Tay bridges. In this country, when the first bridges of wide span were designed by Mr. Stephenson and Mr. Brunel, the question of wind pressure, although duly considered by those experienced engineers, had not assumed the importance which attached to it in the opinion of the designers of the bridges on the American pattern. We have on record references to investigations as to the force of the wind on the Menai bridge, as well as to the wind

action on the suspension bridge of Telford over the same Straits. But with regard to the tubular girders we might almost as well have inquired whether a storm of wind could blow down the walls of Conway Castle, as whether it could shift or overthrow the great tubes. And in the case of the Saltash bridge, where the resistance offered to the side pressure of the wind was comparatively so small, we have seen what were the ponderous dimensions of the central pier. Those were the works of the fathers of our railway system; and whatever may be said of the advance of science since, it is certain that Stephenson and Brunel did not build works which it was unsafe to cross in a storm, were it the fiercest that ever blew in our island. What we feel to be so lamentable—we might use a stronger word—is the comparison of the evidence and arguments offered as to the Tay bridge with the practice of our two great engineers on the one hand, and with the study, as well the practice, of the engineers of the United States on the other. In the discussion to which we have referred, one engineer, Mr. E. W. Young, said that "in every bridge designed by him 40 lbs. wind pressure per square foot had been allowed, and security obtained." "The difficulty in designing girders of very long span is to get width enough to resist wind pressure," observes Mr. Clarke. It would be well if every student who reads the reports made to the Board of Trade by Mr. Barlow and Colonel Yolland, as well as that of Mr. Rothery, were also to read with attention the debate from which we have made extracts. It will strike them, we think, that the degree of knowledge of wind pressure that has been brought to bear on the subject of the Tay bridge by all those who have given advice or evidence on the subject, is very far below that which is common to the engineers of America, of Germany and of France.

THE MAXIMUM AVAILABLE WORK OF GALVANIC BATTERIES.

Translated from La Lumière Electrique.

It may be asserted, without fear of contradiction, that half of the electrical inventions which have been produced within thirty years have been related to electric motors. The failure of these inventions has been due to several causes of which the two principal ones are:

1st. The difficulty of constructing an electro-motor capable of utilizing all the current furnished by a given pile.

2nd. The absolute ignorance, of the greater part of the inventors, of the quantity of work produced by a pile; a quantity perfectly determinate by the laws which govern electro-chemical reactions, and a quantity, moreover, which can never be exceeded.

The inventors of electric motors, working under the conditions in which they generally place themselves, are closely related to the perpetual motion hunters, or to the inventors who seek to drive a locomotive by employing a coffee pot for a boiler.

We propose, in this article, to examine briefly the maximum work produced by the batteries most commonly employed, and to show within what limit this work is produced, so as to prevent stumbling against impossibilities, and to abolish deceptions which are yet too numerous.

We may consider a battery as a veritable *electrical boiler*, furnishing a certain *quantity* of electrical current per second, just as a steam boiler affords a certain *volume* of vapor. This vapor is furnished by the boiler at a certain *pressure;* in like manner, the electricity furnished by the battery possesses a certain *tension* or *electromotive force.*

Take, for instance, one hundred elements of some battery as Leclanché.

We can group these elements in different ways, but we will consider only the two extreme cases:

1st. *Arranged for intensity.*—Connecting the zinc of the first cup to the carbon of the second, the zinc of the

second to the carbon of the third, and so on to the end of the series.

This *intensity* grouping yields an electromotive force one hundred times as great as that of a single cup, but presents at the same time an internal resistance one hundred times as great as a single cup.

2nd. *Arranged for quantity.*—This is accomplished by uniting all the zinc elements to one conducting wire, and all the carbons to the other. In this case the electromotive force is only that of a single element, but the internal resistance has been divided by one hundred, a condition which augments the quantity of the current without increasing the tension. In the first case we have small volume or quantity, but great pressure or tension.

In the second case the tension is feeble but the quantity is considerable. Theory establishes that if in each case the *external* resistance is equal to the *internal*, the work is at a maximum.

The expression for maximum work is very simply stated by the formula of Joule:

$$W=\frac{Q^2R}{9.81} \text{ kilogrammeters.}$$

In which, W is the work, Q is the intensity or quantity of the current expressed in Webers, R the external resistance (equal to the internal) expressed in Ohms. The value of Q is deduced by Ohms formula:

$$Q=\frac{E}{R}$$

R being the total resistance of the circuit, and E the electromotive force expressed in Volts.

Now, in a battery of one hundred Leclanché cells mounted for tension, we have for the electromotive force of each cell (of the new pattern) 1.5 Volts and an internal resistance of 1.13 Ohms. This gives for the value of Q

$$Q=\frac{150}{226}=0.66 \text{ Webers.}$$

The available work becomes

$$W=\frac{0.66^2\times 113}{9.81}=5.02 \text{ kilogrammeters.}$$

According to this, if we suppose a motor theoretically perfect, and a battery to have a constant resistance and to be absolutely unpolarizable, a condition never realized, we see that 100 Leclanché cells can never afford quite the work of one man (6 kilogrammeters).

These calculations, applied to some common forms of battery, yield the following results:

Kind of Battery.	E Electromotive force in Volts.	R Internal resistance in Ohms.	Q Intensity in Webers.	W Available work of circuit in kilogrammeters.
Daniell Battery of high resistance	1.07	10.	0.0535	0.292
Daniell Battery of feeble resist'ce	1.07	0.6	0.89	4.85
Leclanché, new model.....	1.50	1.13	0.66	5.02
Bunsen, medium	2.00	0.41	2.44	25.88
Bichromate, Boudet model...	2.09	0.22	4.75	50.6
Bunsen, Ruhmkorff model...	2.00	0.12	8.33	84.88

These figures show that galvanic batteries considered as sources of motive power can only give satisfactory results when applied to light work requiring a small number of kilogrammeters. The last line of the table shows that more than 100 Bunsen cups of the Ruhmkorff model are necessary to afford a work equal to a one horse-power steam engine.

But, if we take account of the polarization of the plates, the increase of internal resistance, the loss due to imperfect contacts, the hurtful resistances of the conductors, etc., etc., we shall better represent the inferiority of the galvanic pile as an industrial source of motive power.

If, now, we take for the sake of comparison, the figures representing the performance of a Gramme machine of the workshop pattern, we shall see what economy can result from its use in producing powerful currents of electricity.

A Gramme machine of the A pattern, having an interior resistance of 4.58 Ohms, and acting through an external circuit of 4 Ohms, develops an electric current of which the electromotive force is 158.5 Volts, and the intensity 17.5 Webers, representing about four horse-power.

If we wish to replace a similar machine by Bunsen cups of average size, it will be necessary to arrange them in series of 79 for tension to obtain the required electromotive force, and 7 for quantity to have the proper resistance, which requires 553 cups. Such figures dispense with comments.

If we consider the batteries with reference to telegraphic uses, the results look entirely different. The external resistances being very great, compared with the internal, there results a current of low intensity, varying from 2 to 15 milli-webers. Such a current, even upon a circuit of high resistance, represents an insignificant amount of work; the consumption of zinc is small, and the polarization is slight.

It results, then, from these considerations, that galvanic batteries are, as sources of electricity, inapplicable for motive power except in special cases, and their use is more profitably restricted to light and delicate apparatus, such as telegraphs, clocks and the like.

The working of a battery is best when it has the least mechanical work to accomplish. This fact should not be ignored by inventors who seek to obtain from this electric source more than it can give.

ON THE PRESERVATION OF THE ANCIENT BRIDGES IN THE REGULATION OF THE COURSE OF THE TIBER.

By A. VESCOVALI.

Translated from Il Politecnico for "Abstracts" of the Institution of Civil Engineers.

SIGNOR VESCOVALI investigates the problem whether it is necessary, for the protection of Rome from inundation, to demolish or widen the ancient bridges over the Tiber. He regards this question as important, on the one hand, from the point of view of the archæologist; on the other hand, from that of the hydraulic engineeer. If the rigid rule be followed for the execution of the works now in progress to widen the bed of the river from the actual width of 60 or 80 meters, to the given minimum width of 100 meters, it will be necessary either to demolish or to add new arches to the existing bridges. But if the object be so to lower the bed of the river as to restrain the floods within the quay walls, this demolition is not unavoidable.

The ancient bridges of Rome are:—1. Ponte Molle; 2. Ponte S. Angelo; 3. Ponte Sisto; 4. Ponte Cestio (on the right), and, 5, Ponte Fabricio (on the left) of the Isola Tiberina. This list does not include the Suspension bridge, on the site of the Pons Æmilius; the ruins of the Sublician bridge, about 400 yards lower down the Tiber, or those of the Pons Triumphalis, at the bend of the river, west of S. Angelo. The nature of the bed of the river at the points crossed by these five bridges is described as "excavable" under the Ponte S. Angelo, and under the right-hand arch of the Ponte Fabricio. Under the other arches, the bed of the river is covered with the ruins of former bridges, and perhaps with brick platforms of masonry, and is described as "inattackable." The levels of the bed of the river at the five points named are, respectively, 17.16 feet, 12.17 feet, 2.97 feet, 11.94 feet, 8.71 feet, 3.59 feet, and 3.15 feet above the zero of the Ripetta fluviometer, which is 3.17 feet above the mean level of the sea* The third and fourth of these figures apply respectively to the two middle, and the two lateral arches of the Ponte Sisto; and the last two refer to the right-hand and the left-hand arches of the Ponte Fabricio. The channels under the lateral arches of the Ponte Sisto have, however, been recently excavated to a depth of 2.64 feet above the fluviometer zero.

The spans and areas of the apertures of these bridges are given in meters, as it will be more convenient for comparison with the volume of the river than if they are reduced to English feet. They are as follows:

*It is considered that the floods now amount to the volume of 3,000 metric tons per second, the low water volume of the Tiber being 100 metric tons per second. —F. R. C.

	Spans. Meters.	Areas. Meters.
Ponte Molle	71.50	641.52
Ponte S. Angelo	50.20	751.37
Ponte Sisto	69.40	739.70
Ponti Cestio e Fabricio, together	59.20	913.17

It is estimated by Signor Vescovali that it is possible to enlarge the waterway of the Ponte S. Angelo, by deepening the bottom of the channel to 1,084.87 square meters; and that of the two last-named bridges taken together, to 995.05 square meters. The waterway of the Ponte Sisto has been enlarged, by the work now in progress, to an area of 839 square meters, by deepening the channel under the lateral arches by 2.92 meters. Thus the Ponte S. Angelo, which has the least width of waterway of any of the bridges, has the greatest sectional opening in times of flood.

Signor Vescovali then argues that the Ponte S. Angelo does not cause any regurgitation of the water of the river; and states that the level of the water on the right bank of the Tiber, near S. Spirito, is sensibly higher than that on the left in time of flood; a fact for which the rapid curve in the channel accounts. In the flood of October 31, 1873, which rose 13.73 meters above the fluviometer zero, there was a difference of 25 centimeters in the level of the water on the opposite banks.

Signor Vescovali mentions the existence of a mass of ruin which forms a bar across the river between the Palazzo Altoviti and S. Spirito, the crest of which rises nearly to the low-water level at that point, or eight meters above the bottom of the channel under the Ponte S. Angelo.* He considers that it is this bar, and not the bridge, which arrests the flow of the Tiber in this locality; and states that, in the flood of 1870, when the arches of the bridges were entirely under water, the river stood at the same level above and below the bridge of S. Angelo.

The author is, therefore, of opinion that the first thing requisite for the proper regulation of the channel of the Tiber is the removal of those masses of ruin which prevent the river from deepening its own channel in time of flood. He states it to be a canon of hydraulic science, that in all rivers of which the banks are protected from erosion, and the bottom is formed of movable material, the bed becomes lowered by the force of the current in floods, and gradually fills up to its former level in that low-water state, to describe which there is no good equivalent for the Italian word "magra" (feeble). With regard to the Tiber, from the site of the ancient Pons Sublicius to the sea, the bed is composed of material removable by a rapid current. Above this point, Signor Vescovali is of opinion that the actual height of the water is artificially kept up by the ruins, which prevent the scour from having a proper effect on the bed of the river. He states that when the tubular piles for the bridge for the Civita Vecchia railway were driven, fragments of pottery, ancient lamps, and numerous *stili*, of bone and ivory (with which the Romans were accustomed to write on their waxed tablets), were found in a stratum 1 foot deep which crosses the channel of the river at a depth of about 2 meters below the zero of the Ripetta fluviometer. He considers that the stratum indicates the ancient level of the bed of the Tiber, and that in time of flood the level was normally excavated by the current down to a depth of 3 meters below the present bottom of the Ponte Cestio, and 2 meters below that at the Ponti Fabricio e Sisto.

Signor Vescovali, however, is of opinion that the ancient bridges over the Tiber were founded on platforms of masonry built across the bed of the river, which was probably partially diverted during the progress of the works. He gives reasons for this view, but insists on the necesity of ascertaining the fact, before proceeding with the costly works now in progress. He considers it probable that these platforms now exist, at a depth sufficient to allow of ample water-way being kept open through the bridges, if the ruins that encumber the bed of the river are removed. His opinion is that the now existing width of 50.20 meters at the Ponte S. Angelo will be ample to carry off the water that comes through the newly-regulated channel 100 meters wide, in consequence of the greater depth that the scour will then produce beneath the archways.

Signor Vescovali cites the example of the engineers Lombardini and Brighenti,

*Which would be down to the mean level of the sea.

who, in order to reduce the heights attained by the floods of the Arno in Florence, proposed, not the rebuilding of the bridges, but the removal of the masonry platform on which they stand, in order to allow of the excavating action of the scour of the river. He points out however, the danger of undermining the piers of a bridge by such an operation; and remarks that the nature of the soil through which the Tiber flows is such as to have rendered necessary, in the recent construction of bridges, to cross its bed, piling to a depth of nearly 40 feet (12 meters) below the level of low water. Thus, while still in ignorance of the exact system on which the ancient bridges over the Tiber were built, Signor Vescovali holds that the bed of the river through Rome has been notably raised.

The council of Public Works propose a clearing of the bed of the river, limited to a level of 1.50 meter above the zero of the fluviometer at the Ripetta, from which point the profile is to be horizontal as far as the Ponte Molle, going up stream, and to fall with the gradient of 0.40 per kilometer towards the sea. According to this plan, the bed of the river at Mormorata (below the site of the ancient Sublician Bridge) will be 0.10 meter above the zero of the fluviometer. At the two island bridges it will be 0.29 meter above, and at the Ponte Sisto, 0.50 meter above that fixed point. Signor Vescovali urges that the depth requisite below the bridges ought to be at least 3 meters below the zero of the fluviometer. He holds that if the channel is clear to this depth —which is the level of the platform of the Ponte S. Angelo, and of the right arch of the Ponte Fabricio—ample waterway will be secured for the river without demolition or enlargement of the bridges. He is of opinion that the course of the channel should be regulated, according to the plan of Signor Cesarini, from the Ponte Molle to the Canal of Fiumicino; and that in consequence the low-water level would be reduced 4 meters at Ripetta; that a depth of 5 meters would be retained in times of drought; that the level of the floods would be reduced from 4 to 5 meters below that attained in 1870; that the level of the subterranean waters in Rome would be lowered by 4 meters; and that navigation would be practicable from the sea to the city of Rome.

NOTE.—As the zero of the Ripetta fluviometer is only 0.97 meter above the mean level of the sea, the bottom of the channel of the Tiber in Rome, according to the above suggestion, would be 2.03 meters below sea level. Referring to the account given (Minutes of Proceedings Inst. C. E., vol. lvii., p. 360), of the gradual depression of the eastern coast of Italy, the question arises whether a similar movement in the valley of the Tiber may not have occurred, in which case the increased damage caused by floods would become readily intelligible.

ON THE LAW OF FATIGUE IN THE WORK DONE BY MEN OR ANIMALS.

From "Nature."

THE Rev. Dr. Haughton, of Trinity College, Dublin, has recently brought to a conclusion a series of papers on Animal Mechanics published in the *Proceedings* of the Royal Society. The ninth of these papers was appointed the Croonian Lecture for the present year, and the tenth paper closes the series.

The most important subject involved in these papers is the experimental determination of the law that regulates fatigue in men and animals, when work is done so as to bring on fatigue.

Many writers, such as Bouguer, Euler and others, have laid down mathematical formula, connecting the force overcome with the volocity of the movement; but these theoretical speculations have never received the assent of practical engineers.

Venturoli points out a method of observations and experiments which would serve to determine the form of the function which expresses the force in terms of the velocity, after which a few carefully planned experiments would determine the constant coefficients; and he adds that "such a discovery would be of the greatest usefulness to the science of mechanics, upon which it depends, how to employ, to the greatest possible advantage, the force of animal agents."

Dr. Haughton believes that he has found the proper form of this function, by means of experiments, and sums it up in what he calls the *Law of Fatigue*, which he thus expresses:

The product of the total work done by the rate of work is constant, at the time when fatigue stops the work.

If W denote the total work done, the law of fatigue gives us—

$$W\frac{dW}{dt}=\text{const.},$$

or

$$\frac{W^2}{T}=\text{const.} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The experiments made by Dr. Haughton, from 1875 to 1880, consisted chiefly in lifting or holding various weights by means of the arms; the law of fatigue giving, in each case, an appropriate equation, with which the results of the experiments were compared. When the experiments consisted in raising weights on the outstretched arms, at fixed rates, the law of fatigue gave the following expression—

$$(w+a)^2n=A \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where w, n, are the weight held in the hand, and the number of times it is lifted, A is a constant to be determined by experiment, and a another constant depending on the weight of the limb and its appendages.

The equation (2) represents a cubical hyperbola.

The *useful work* done is represented by the equation—

$$wn=\frac{Aw}{(w+a)^2} \quad . \quad . \quad . \quad . \quad (3)$$

This denotes a cuspidal cubic, and the *useful* work is a maximum, when $w=a$, or the weight used is equal to the constant depending on the weight of the limb and its appendages.

When the weights were lowered as well as raised at fixed rates, and no rest at all permitted, the law of fatigue became—

$$\frac{n(1+\beta^2t^2)}{t}=A \quad . \quad . \quad . \quad . \quad (4)$$

where n, t, are the number and time of lift, A is a constant depending on experiment, and β is a constant involving the time of lift (τ) at which the *maximum* work is done.

Equation (4) denotes a cuspidal cubic.

When the weights are held on the palms of the outstretched hands, until the experiment is stopped by fatigue, the law becomes—

$$(w+a)^2t=A \quad . \quad . \quad . \quad . \quad (5)$$

where t is the whole time of holding out.

This equation denotes a cubical hyperbola.

The *Law of Fatigue* seems, in itself, probable enough, but of course its real value depends on its agreement with the results of experiment.

If W denote the total work done and R the rate of work, the law becomes, simply—

$$W\times R=\text{const.} \quad . \quad . \quad . \quad (6)$$

If different limbs, or animals, were used, each working in its own way, and under its own conditions, the *Law of Fatigue* would become—

$$WR=W_1R_1+W_2R_2+W_3R_3+\&c. \quad . \quad . \quad (7)$$

and the problem for the engineer would be, so to arrange the work and rate of work of each agent employed, as to make the *useful work* a maximum, the work both useful and not *useful*, in all its parts, remaining subject to the conditions imposed by equation (7).

In using equation (5) in his concluding paper, detailing the results of experiments made on Dr. Alexander Macalister, Dr. Haughton treats a as an unknown quantity, and finds from all the observations its most probable value to be—

$$a=5.68 \text{ lbs.}$$

This result was compared with that of direct measurements made on Dr. Macalister himself, and indirect measurements made on the dead subject, from all of which Dr. Haughton concluded the value of a to be—

$$a=5.56 \text{ lbs.} \pm 0.125 \text{ (possible error)}.$$

This result agrees closely with that calculated from the law of fatigue.

It should be added that a proposal was made by Dr. Houghton to Dr. Macalister to make the experiment conclusive by direct amputation of his scapula, a course which he, unreasonably, objected to, as he draws the line of "vivisection" at frogs.

DETERIORATION OF IRON IN MARINE STEAM BOILERS.*

By JOHN A. TOBIN, Engineer Corps United States Navy.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

THERE is, perhaps, no single subject within the wide range of steam engineering which has invited the earnest consideration of the engineer and chemist more than that of the deterioration of iron in boilers.

Many wild theories and hasty conclusions have been published by those who, apparently, could not have given the subject much thought, and many may have been misled thereby, as to the true cause.

In this paper I do not pretend to advance any new theories, but will confine myself to a few facts gleaned from experience, and call attention to some others bearing upon the subject, which will be found in several of the leading engineering journals, and in the Boiler Committee Reports of the English Government.

I will briefly mention the circumstances connected with an extraordinary case in the bottom sheets of the steam drums of the United States Steamer Swatara, the first sloop of war fitted with a compound surface condensing engine, with seamless brass condenser tubes tinned on both sides. Ten cylindrical boilers furnish steam to the engine through copper steam pipes. Situated in the upper spandrels, between each pair of boilers, are the steam drums—thickness of shell $\frac{3}{8}$ inch. The drums are connected with the boilers by untinned copper pipes. After two and a half years service, a leak developed in the bottom of one of the drums; its condition was examined and found to be badly deteriorated. This fact prompted an examination of the remaining drums, and they were found to be in a similar condition. As high as the water from condensation had risen, corrosion was found to have been very destructive, particularly along the bottom, which was covered with a dark greasy sludge mixed with a noticeable quantity of oxide of iron. Not till each defective sheet was cut out and passed through the rolls were the different kinds of corrosion clearly defined, such as pitting and confluent honeycombing, from the merest impressions to a depth equal to the thickness of the sheet. The wrought iron bolt heads, which held the main drain valves, were completely wasted, while the rivet heads adjacent were simply coated with oxide of iron.

In the month of December, 1876, I sent to Professor Wm. Ripley Nichols, Professor of Chemistry in the Massachusetts Institute of Technology, a small sample of deposit from one of the drums, together with a specimen of one of the defective sheets, and all the particulars that would have any bearing upon the case; although, at the time, busily engaged with school work, he was good enough to find time to examine the specimens, but not as thoroughly as he would have liked. In the sample of deposit, he reports not finding any copper, but upon the examination of the specimen of plate he states as follows:

"I find in places a quantity of a greasy deposit containing copper, apparently in combination with fatty acids. I have not had time to prove in just what form of combination the copper is. I dare say there are several compounds: ollate, stearate, and palmitate. Whether there is any acetate of copper I cannot say, but from the greasy deposit I obtained good tests for butyric acid, so that there is some butyrate of copper no doubt. The copper compounds in contact with the metallic iron would be reduced to metallic copper, and a corresponding amount of iron would be oxydized, and then there would be a galvanic action established between the particles of copper deposited and the iron of the plate. The inner surface of the drums is no doubt continually wet, and on account of spray carried from the boilers the water is charged more or less with saline matter, as I inferred

* Read before the Society of Arts, Mass. Institute of Technology.

from examination of the deposit, this was mainly, although not wholly, hydrated oxide of iron. The presence of the saline solution would favor the galvanic action if the copper were once set free. The greasy matter would, however, protect the copper compounds from decomposition, and it is not, therefore, a matter of surprise that copper should be found in combination. I found, however, by examining the scale on the plate, that there were actually *metallic particles* of copper present, and it seemed to me that this alone might account for the effects which were observed."

In reply to certain questions he further states: "Olive oil is a mixture of three chemical compounds: olein and palmitin, which make up the bulk of the oil, and stearin, which is present in small amounts only. These three compounds, which are neutral bodies, are called in chemical langauge as follows: Olein is oleate of glyceryl; palmitin is palmitate of glyceryl; stearin is stearate of glyceryl. As nitric acid is related to nitrate of soda, and as sulphuric acid is related to sulphate of lime, in the same sense, oleic acid is related to olein and palmitic acid to palmitin. If olive oil (call it a mixture of olein and palmitin) be heated with hydrate of sodium, there is formed oleate and palmitate of soda—which we call soap—and hydrate of glyceryl, which we call glycerine. If carbonate of soda be used, the soap formed is just the same, also the glycerine, while the carbonic acid escapes. Almost all the natural fats are constituted similarly to olive oil; some contain more stearin, such as beef fat, for example, and all can be saponified by alkalies. The fats and oils may also be decomposed by superheated steam, and in the manufacture of the so-called stearine candles (which are really made of a mixture of stearic and palmitic acids), this process is used on a large scale. Under these circumstances, from the stearin and a portion of the water, are formed stearic acid and glycerine. From the palmitin and water are formed palmitic acid and glycerine, and from olein and water there are formed oleic acid and glycerine. The temperature of the steam in the cylinders is no doubt sufficient to bring about partial decomposition of the oil used for lubricating, and attention has been recently called (*Iron*, Sept. 23, 1876), to the enlargement of the cylinders, caused by such decomposition of the grease, a fact which has been previously noticed and noted. In your case, however, it does not seem to be simply the direct action of the acids upon the iron, although this probably plays a part, but it would appear that the acids attack the copper, forming oleate and palmitate of copper, and then, by the contact of these compounds with the iron, there are formed the corresponding iron compounds, oleate and palmitate of iron, and the copper is set free. When once the copper is set free in the metallic state, there is formed, as it were, a multitude of galvanic batteries which result in the destruction or oxydation of the iron. As to the butyric acid: In some fats there occur a compound butyrin—butyrate of glyceryl—corresponding to butyric acid, and from which butyric acid may be obtained in the same way that oleic acid is obtained from olein. This compound (butyrin) has been reported as found in olive oil, and the butyrate of copper or iron, which I found, may be due to this fact, or to the decomposition of oleic acid. It is not improbable that if I had time and a sufficient quantity of the material, it would be possible to show the presence of the deposit in your drums of the compounds of various other acids." Professor Leeds, Professor of Chemistry at Steven Institute of Technology, Hoboken, N. J., very kindly examined some of the same deposit, and verified the statement of Professor Nichols so far as to show the presence of a very minute quantity of copper in connection with the acids produced by the decomposition of the olive oil and tallow. Tallow was used at times, with olive oil, during the first year of the cruise, for internal lubrication of the cylinders and valves. During the following eighteen months, olive oil was the one lubricant used. After new bottoms were put in the drums and wrought iron connecting pipes substituted for the copper ones, plates of zinc were suspended in each drum to arrest chemical action. Their use was discontinued after one trial, owing to the trouble arising from the obstruction of the drain pipes by the oxide and other compounds of zinc which were formed,

and the method of cleaning and thoroughly draining each drum once a month for eighteen months was resorted to with most excellent results.

The approximate time it took the zinc suspended in steam of high or low pressure to oxidize, so as to leave no apparent element of metallic nature, was carefully noted by the officer of the watch in the steam log-book as follows: Nine days at sixty pounds pressure plus twenty-five days at an average pressure of twenty-five pounds in four drums; while in the sixth drum it was nearly sixty days decomposing under a pressure of twenty-five pounds. In the latter case, there was no connection with the cylinders.

In the pursuance of further enquiries into the alleged causes of the deterioration of iron in boilers, I was permitted, by the kindness of Professor Nichols, to examine the recent reports of the Boiler Committee, appointed by the British Government. In the thorough and careful experiments conducted by them at Sheerness, to determine the corrosibility of various irons and steels when under conditions similar to those in which marine and land boilers are worked, it was found that the per centage in favor of mineral oil was 46; this result was obtained by filling tubes with liquids and lubricants, containing, respectively, tallow and mineral oil, in which were placed discs of iron. The rods and discs in the tubes containing tallow and vegetable oil, were found to be coated with a black substance which was very tenacious in the water, and harder in the lower portion of the steam space, while the mineral oil retained its fluidity, and only required to be wiped off with a cloth.

The committee mention the experiments by Professor A. W. Hoffman of the College of Chemistry, England, in the interest of Messrs. Humphreys & Tennant, on the destructive agency of fatty acids, as follows: "Rods of different varieties of iron were placed in iron tubes with hermetically closed caps, the tubes being previously charged with water and stearic acid; the latter having been separated from tallow by the ordinary process of lime saponification. On opening them after being exposed for three weeks to a temperature of from 264° to 285°, corresponding to a pressure of from 2½ to 3½ atmospheres, the inner surface of the tubes, as well as the iron rods, were found to have been corroded in a great degree. A large proportion of oxide of iron was found in conjunction, and apparently in combination with the fatty acid floating in the liquid."

He also states in support of his theory as opposed to that of galvanic action, induced by iron and copper together being brought into contact with water and fatty acids, an experiment in Percy's metallurgy:

"For this purpose clean iron rods were surrounded perfectly by metallic copper coils, in such a manner that the two metals were nearly everywhere in perfect metallic contact; they were then introduced together with fatty acids and water into glass tubes, and exposed to a temperature of about 264° Fah. In some of these experiments distilled water was used, and in others salt water; after the lapse of eight days the tubes were opened, when on each of them a minute quantity of hydrogen was found. The iron, where not covered with the copper wire, had become coated with a dark brown deposit, perfectly similar to that which appears on iron when treated with water and fatty acids alone; the copper had remained metallic, and when the coil was removed, the iron where it had been covered by it, remained perfectly metallic, and no corrosion could be detected." Professor Hoffman states that the foregoing experiments strongly confirm him in the opinion "that the corrosion of iron in boilers worked with surface condensation is due to the direct action of free fatty acid." In furtherance of the support of the above opinion, he mentions the examination of several deposits from boilers of vessels worked with surface condensation as follows: "In but one of the samples of deposit was found any trace of copper. In the absence of accurate information upon the particular circumstances under which cupriferous deposits were found, it would be useless to speculate upon the origin, but the occasional occurrence of small quantities of copper in this description of boiler deposits, cannot, I conceive, justify the hypothesis that it is an essential condition of the corrosion so con-

stantly occurring where copper is entirely absent."

To resume the report of the committee: "They find that during the time the grease remains in contact with the copper or brass surfaces of the condenser tubes, there may be formed a grease compound containing copper in an oxidized state. The compound may be either oleate or stearate or other organic salt of copper, and is the result of the joint action of a fat acid and air upon the copper in the tubes. Such a compound is only produced when either tallow or vegetable oils, or any like substances capable of saponification, are used as lubricants; the so called mineral oils being incapable of contributing to its formation. To illustrate this difference, coils of sheet brass were placed in common tallow, and other similar coils in mineral oil, and heated day by day for four months, air having free access to the surfaces. The sheet brass in the tallow weighed 1029.30 grains, and lost 14.10 grains, and the tallow was colored green, while that which was placed in the mineral oil (weight, 1101.40 grs.) lost only .20 grains, and the oil grew darker. It is believed that the amount of corrosion supposed to have been contributed by copper or its compounds has been greatly over-estimated, and the evidence of witnesses upon this point was extremely indefinite, especially as to the forms in which the copper reached the boiler. That it does so, there can be no doubt, because the feed pipes are sometimes considerably acted upon, chiefly at the bends or elbows, and the tallow or saponifiable oil has been carried by the steam from the cylinders to the condensers, and accumulates upon the surfaces of the tubes, the greater portion of which may be transferred to the boilers with the condensed water."

In 1873, while Dr. Jerome H. Kidder, of the U. S. N., was on duty at the Naval Laboratory, New York, a specimen of the substance that came from the condenser at Hecker's Flour Mills was examined by him, which, in the course of experiments, seemed to have established the presence of oleate of copper as the probable cause of the destruction of boiler tubes. The result of his experiments were communicated to VAN NOSTRAND'S ECLECTIC ENGINEERING MAGAZINE in February, 1874, the substance being as follows: The presence of oleate of copper is accounted for in the decomposition of the olive oil, along the line of friction between the piston and sides of the cylinder, into oleic acid and glycerine. A small portion of the oil then having become decomposed into oleic acid and glycerine, and the latter passing through the condenser first harmlessly, and the former somewhat later. He supposes the oleate of copper to be then formed in the condenser, which appears as bright green greasy masses, which are carried from the condenser into the boilers, and being quite insoluble in water, the masses accumulate (in accordance with a familiar law) in those parts (at the ends of the tubes) that the most corrosion is found, settling upon one of the iron tubes a mass of oleate of copper adheres thereto, and, favored by the conditions of high temperature and pressure, the deposition of copper and absorption of iron begins. If the oleate of copper were soluble in the water of the boiler, the erosion of the tubes would be uniform over their entire surface. Being insoluble, however, its action is confined to the surface of contact, hence the small holes characteristic of this kind of injury. Since, as shown by experiment, copper thus deposited will remain adherent only to perfectly smooth iron, and since boiler tubes are never in this condition, the copper is probably removed by the action of water as fast as deposited, leaving constantly a fresh iron surface for further action. Whether the action, which takes place in the boiler, be galvanic or chemical, is uncertain, if indeed, there be any essential difference between these two modes of action, other than a difference of degree. Whether the percentage of sulphuric acid that is sometimes used in the manufacture of merchantable tallow (and not thoroughly cleaned of the same) has an injurious effect upon iron, is a question that seems to have had little consideration. Professor Dassaunce, of the French Academy of Science, states in his general treatise on the manufacture of soap, that in the manufacture of tallow and lard oil, a quantity of concentrated sulphuric acid is used to expedite the process of extracting all the tallow from the dregs. The follow-

ing are the proportions given: 1,000 pounds of tallow, 25 gallons of water, 10 pounds of concentrated sulphuric acid. Mention is made of the same mode of treatment in M. V. Regnault's elements of chemistry. The fats, after being heated by steam, in boilers, are first treated with a quantity of concentrated sulphuric acid, which varies from 6 to 15 per cent., according to the nature of the fat.

The committee to determine the destructive action of air upon iron, placed iron discs in two groups of tubes, the circumstances being identical as regards the water and lubricants. In one case the air was excluded, and in the other admitted weekly, with a result of 19.7 per cent. in favor of the exclusion of air. It was also found that perfectly dry air has no action upon compact iron at the ordinary temperature; neither has water when perfectly free from air, and from a series of experiments to illustrate the action of oxygen upon iron immersed in water under different conditions, it appears that pure distilled water, perfectly free from solid matter, allows of more corrosion than sea water, and that the oxydation which has been ascribed by many of the witnesses, and others, to the action of pure water, in itself considered, should be attributed to the oxygen contained in the air dissolved by such water, the water acting as a means of transfer for the oxygen to the iron. A good illustration of the destructive action of oxygen upon iron is by Rand C. Stieman, in No. 124 of the *Scientific American* supplement, in which he gives description of his invention to yield a product which shall be equal in quality and price to "English Red," and to the native ochre obtained by mining in France. The process consists in the alternate action of fresh water and atmospheric oxygen upon wrought iron turnings. So destructive is the action, that in 24 hours it was found to yield about 1.5 per cent. of hydrated oxygen. A ton of borings thus treated for one week would yield 2 cwt. of the product.

Concerning the use of zinc as a preventative of corrosion, the committee found the evidence to be both conflicting and defective. "The results obtained from some experiments by them, show, that when properly applied it does protect iron and steel under the ordinary conditions of working, from a large proportion of the corrosion to which they would have been subjected had the zinc not been present. Apart from any consideration as to the existence of galvanic action in boilers, the protective value of zinc may be stated as follows: If a boiler is worked in the ordinary manner with sea water, its exposed surfaces will be vulnerable to the action of all the influences which may be present capable of affecting iron. But if zinc be introduced and applied in the manner which has already been pointed out, *i. e.*, perfect metallic continuity insured between it and the iron, galvanic action is set up between the two metals, and the latter is compelled by the presence of the former—it being of a more electro-positive nature—to assume a negative condition towards corrosion or oxydation. Such being the case, the metallic condition of the iron is preserved at the expense of the zinc, which loses in course of time its metallic nature by oxydation, in which latter condition it ceases to afford protection, and must, therefore, be renewed at intervals. In cases where this metallic continuity has not been effected, the zinc would share with the iron surfaces of the boiler any corrosive action that might be present, in proportion to the surfaces exposed, which in any case would be relatively small; there would be no electro-chemical relation between metals, and the different results observed by marine engineers may have depended upon the fortuitous circumstances that, in some cases, metallic continuity had been unintentionally effected in suspending the zinc from the stays of the boiler.

"This seems to be a very probable explanation of the discordance of the opinions held by many as to the protective value of zinc. A uniform and more reliable method of applying it is desirable, as in the present practice of suspending zinc from the stays, there may or may not be metallic continuity between it and the surfaces to be protected."

Engineer-in-Chief, William H. Shock, of the U. S. Navy, recently issued instructions to the engineer officers of naval vessels to make careful experiments with zinc to determine its practical

value in preventing or arresting the interior corrosion of marine boilers. It is in place to call attention here to a fact mentioned in a report by Colonel Kurtz and Captain Brown of the U. S. Army Engineer Corps, to the Engineer-in-Chief of the Army upon the durability of zinc, and the effect of sea water and exposure upon iron pile shafts of the Brandywine shoal light-house, in which they state that of the zinc collars on the shafts, placed there twenty-five years ago, ten are visible above low water mark on as many piles. There seems to be very little doubt but much of the irregular corrosion of wrought iron is due to want of homogeneity; this, Professor Hofman explains by taking a plate of wrought iron presenting a clean and apparently uniform surface, and covering the surface everywhere with an equal depth of acid, when it will generally be found to yield very unequally in different parts to the action of the solvents by becoming furrowed, and, in some parts, pitted with deep excavations, which ultimately become peforated often as circular as if drilled with a tool. Again, the mere action of the atmosphere reveals unequal texture of the metal, as a high polished plate of iron, when allowed to rust in the air, is observed to be very irregularly attacked. Some parts of its surface retain their first lustre long after other parts have become thickly coated with oxide. Any one acquainted with the ordinary manufacture of wrought iron cannot be surprised at the result, it being an aggregate of fibres mechanically heated and welded together, but not blended into homogeneity by *fusion*. The red-hot ball in the puddling furnace is but a sponge filled with a semi-fluid silicious slag, which is squeezed out, more or less perfectly by mechanical pressure. The presence of the merest traces of these impurities between the adjacent fibres of the iron may prevent their welding, and leave an opening for chemical agency to penetrate. The passage of the iron through the rolls may mask, but cannot obliterate, such exposed points, which, though imperceptible to the naked eye, may, under chemical attack, become the pits and perforations we are seeking.

Of the methods proposed for the preservation of iron and steel are those known as the hot steam process and hot air processes. To Professor Barff, of Kensington, England, according to the English *Engineer*, is due the credit of first reducing the work of protecting iron by the hot steam process. The former method consists in exposing the metallic surfaces, while heated to redness, to the action of superheated steam, thus producing upon their surface the magnetic oxide of iron, which, unlike common rust, possesses the characteristic of permanency, and adheres closely to the metallic surface below. The magnetic oxide is practically insoluble in sea water and other weak solutions.

The hot air method is accredited to Mr. G. Bower of St. Neats, England, and though the results produced are substantially the same, the methods of manipulation employed are very different. The use of steam is dispensed with, and he relies on the air for his supply of oxygen in forming the coating of magnetic oxide. As to the relative value of the two systems, and their advantages and disadvantages as applied to manufacturing purposes on such large and important work as boiler making and armor plating, by the possible interference with the coating on the rivet heads and seams that require to be caulked, and the working of iron, is a matter that can only be concluded by careful experiment.

As early as 1869, Colonel Paine, of the Engineer corps of the army, produced, by a process of his own, a surface of magnetic oxide upon steel measuring tapes, which has proved a perfect protection from further rusting, and the tapes are yet in good condition.—(VAN NOSTRAND'S MAGAZINE, June, 1878).

One of the many causes of the deterioration of marine boilers is due to the sudden changes of temperature, produced by pumping in cold water in place of that blown out to keep the density in the boiler within certain low limits, thereby causing leaks from unequal expansion and contraction. As to limit of density of water in a boiler is a question upon which engineers seem to be at variance. It appears, however, from the experiments of M. Cousti, that the sulphate of lime, which is contained in sea water in a large proportion at a temperature of 60°, is precipitated upon an in-

crease of temperature, so that at 212° merely traces are left. In consideration of the foregoing, it would seem that limiting the density of the water in the boilers to $\frac{3}{32}$, less sulphate of lime would be deposited, the life of the boiler prolonged, and better economical results obtained.

The evidence taken by the committee show that in many steamers the density of the water in the boilers is carried even beyond $\frac{3}{32}$, and in concluding their report on this subject, state the density should in no case exceed three times, nor be less than one and a half times that of sea water. As so much difference of opinion does exist as to the proper density at which to carry the water in marine boilers, it is to be hoped that a series of experiments will be instituted in this country to determine the merits of so important a question.

As to the cause of the rapid determination of the steam drums of the U. S. S. Swatara, there can scarcely be any misconception, but that it was due to the action of fatty acids found in the deposit, and to the galvanic action, if any, induced by the presence of copper, free and in combination.

The presence of copper in combination with fatty acids undoubtedly occurred from the action of the acids upon the copper pipes, while the engines were at rest. (Surgeon J. H. Kidder, of the U. S. Navy, suggested in an article published in VAN NOSTRAND'S ENGINEERING MAGAZINE in 1873, that oleic acid might have been set free by the high temperature of friction between the piston and cylinders, whereby the film of oil used for lubricating was decomposed into oleic acid and glycerine, attacking the copper exhaust pipes and condenser tubes on its passage to the boilers). That mentioned by Professor Nichols as "minute particles" was from the bends of the pipes, at which point the planished surfaces were wholly destroyed while undergoing the severe strain of bending.

Too much care cannot be taken to keep the boilers and steam drums, when not in use, free of water, as the alternate wetting of the parts cannot but work great injury. This Mr. Steiman proves so clearly in his experiment on the alternate action of atmospheric oxygen and fresh water upon wrought iron turnings.

Every cruising ship in the U. S. Navy, is, where space will permit, fitted with an auxilliary boiler of the low pressure type, and used exclusively for heating ship and distilling water. The design is such as to render it readily accessible in all its parts for cleaning and repairs, thus lengthening the life of the main boilers by being kept free from any injurious deposits from sea water, and the unequal expansion and contraction occasioned by the use of one of several furnaces of a large marine boiler, which is oftentimes the case, for the purpose of distilling or heating ship.

In concluding this paper, attention is called to the fact that the longevity of so important a portion of the power as the boilers of a war ship, depends, not only upon being managed by a full complement of efficient and able engineer officers, but, in a great measure, upon their construction and accessibility for cleaning and repairs. So far as material and workmanship are concerned they may be faultless, and yet, certain important points overlooked, which greatly impair their circulation and evaporative efficiency.

ON THE CONSTANTS OF THE CUP ANEMOMETER.

By Rev. T. R. ROBINSON, D. D., F. R. S., &c.

From Papers of the Royal Society.

IN a previous paper the author detailed experiments made by attaching anemometers to a whirling machine, and the conclusions to which they led. He was, however, doubtful of the accuracy of the method, and proposed one depending on the action of natural wind. He has tried this, and he thinks successfully. Two instruments of the Kew type, differing only in friction, were established 22 feet asunder on the roof of the house and 16 feet above it; the number of turns made by each, and the time, were recorded by a chronograph, and from these, v and v',

the velocity in miles per hour of the centers of the cups was known.

The friction of one of these (K) was constant; that of the other (E) was varied by applying to a disk on its axle Prony's brake, which was connected with a spring balance whose tension was recorded during the time of experiment by a pencil moved by clockwork. Thus the mean friction was obtained. It ranged from 353 grains to 4,982.

The equation of an anemometers motion is

$$V^2+v^2-2Vvx-\frac{f}{a}=0$$

where V is the unknown velocity of the wind, a and x two constants which are to be determined. Each observation gives two equations in which there are four unknown quantities, for it is found that the value of V changes from one instrument to another. This is partly owing to eddies caused by the buildings, but also in great measure to irregularity of the wind itself. It is, however, also found that these wind-differences are as likely to have + as − signs, and, therefore, it may be expected that their sum will vanish in a large number of observations. The ordinary methods of elimination fail here even to determine with precision a single constant, and he has proceeded by approximation.

Assuming the value of a given by the actual measurements in his paper = 15.315 at 30″ and 32° for 9-inch cups, and that there is no resistance as v^2 except that in the equation, and assuming an approximate value for x, we can compute V and V′. The difference between these must be due to an error in x and to w the wind error, and taking the sum of a series we have

$$S(V'-V)+Sw=\Delta x\times S(e-e');$$

$$e \text{ being} -\frac{V}{\sqrt{x^2-1+\frac{f}{av'^2}}}.$$

If the observations are sufficiently numerous $Sw=0$, with the assumed $x+\Delta x$ thus found, recompute the V till the sum of V′−V is insensible, and the final x will give V with a high degree of probability. Twenty-one observations gave a value of x considerably larger than what was obtained with the whirling machine, and of course the limiting factor (that when v' is so large that $\frac{f'}{av'}$ may be neglected). It is for the Kew type 9″ cups 24″ arms=2,831. In this series the differences are so evidently casual as to show that neither a or x change with v.

With this x, K gives the true value of V at it; therefore, if any other type be substituted for E′ it is easy to find its x, for its a is as area of cups, its f′ is known, and assuming its x' and computing as before, we get similarly its Δx. He tried five different types and obtained very unexpected results, for he found that the x varied as some inverse function of the diameter of the cups and of the arms. He gives its values:

No. 1.	Original instrument....	12″	cups	23.17	arms,	x=1.5880,	limit	2.812
" 2.	Kew.....	9	"	24,	"	1.5919,	"	2.831
" 3.	"	9	"	12,	"	1.7463,	"	3.035
" 4.	"	9	"	8,	"	2.1488,	"	4.051
" 5.	"	4	"	26.75	"	1.8587,	"	3.425
" 6.	"	4	"	10.67	"	2.5798,	"	4.958

No. 6 is similar to No. 2, and it might be expected that their constants would be equal. The cause of these differences is partly the eddies caused by the cups being more powerful when the arms are short, but still more the presence of high powers of the arm and diameter occurring in the expressions of the mean pressures on the concave and convex surfaces of the hemispheres. In the present state of hydrodynamics we cannot assign these expressions, but we know enough to see that such powers may be present.

As each type of anemometor has its own constants, the author would suggest to meteorologists the propriety of confining themselves to one or two forms. For fixed instruments he considers the Kew one as good as any, and would wish to see it generally adopted. For portable ones he has no experience except with Casella's 3″ cups 6″ arms, which he found very convenient; he has not, however, determined its constants. Some selection of the sort seems necessary if it is wished to have an uniform system of wind-measures.

THE ARTS AND INDUSTRIES OF CHINA.

By JAMES A. WHITNEY, LL. D.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

NOTHING affords more facile proof of the common origin of races now remote from each other, than does the identity of terms applied to the necessaries of life, and the similarity of the rude implements by which the simple operations of industry are performed. The former has shown the primal unity of Sanscrit and Zend, and traced to its furthest source the origin of the Aryan peoples. The latter shows that the arts of craftsmen had reached a certain excellence before the European parted company with the natives of India. But by neither of these clues can any connection be traced between China and other lands. The language, even in its simplest roots, has no analogue; and the implements of industry have characteristic forms that demonstrate their orgin to be distinct. The anvil of the Chinese smith is not flat like the anvils of other countries, but convex on its face or working surface; and the bellows of a Chinese forge, instead of moving vertically, has a horizontal stroke. The paper of the Chinese is thin and weak; is printed on one side only, but doubled to present a folded edge at the rim of the the leaf, and a printed surface on either side. The chain pump of China has a square barrel, that of other lands is cylindric. Brass is made elsewhere by melting together copper and zinc in a crucible, in China, by suspending thin sheets of copper, heated almost to melting, in the vapor of molten zinc. The German silver of Europe is made by combining the materials in their metallic condition, its Chinese equivalent by mingling the ores of the metals and reducing them together to produce the alloy. Spangles are made, not by cutting or stamping from sheet metal, but by flattening wire first bent into annular form. Pewter vessels are not cast, but are shaped by hammering upon a block. The primitive mill used in many countries —in Normandy, for crushing apples for cider, in South America, for pulverizing ores, in our own country, for powdering the scoria of assaying pots—and composed of a wheel traveling in a groove or channel, has, among western nations, its wheel running continuously in a circular track around a vertical axis; in China, its wheel working to and fro in a semi-circular track, and around a horizontal center of movement. Chinese lanterns are not made of horn, like those of the Romans, or of perforated metal, as long since in our own country, or of glass, as is now universal, but are of varnished paper stretched on bamboo frames, sometimes of little cost for the multitude, sometimes of great intrinsic worth, and blazoned with titles, for the mandarins. The domestic industry of other lands has obtained the healthful acid of vinegar from the acetic fermentation of the sweet juices of fruits; the Chinese, by placing in water the sea polypus found along the coasts. Fish culture, now a matter of government solicitude in our own and other countries, is old in China, but the Chinese fish culturist puts the spawn in an eggshell and places it under a setting fowl, and after due delay breaks the shell into water warmed by the sun. These are not trifles. They show that in the earliest period of her existence China drew nothing from other lands. In what she required she originated all, she imitated nothing.

And even in the things that for ages have been common in other countries, we find that in unnumbered instances their paralellism with those of China is of but modern date; that they, too, at former periods have shown by their use in China, and nowhere else, that they were but further proofs of the self-sufficing and self-supplying character of the Chinese mind. It was this that discovered the polarity of the magnetic needle and applied it to use in the compass, and obviated its dip by the simple device of placing its weight below the point of suspension, and it was this, too, that first perceived, and made allowance for, the variation of the needle from

the true pole. It was to this that was due the invention of printing and its perfection to the highest degree permitted by the language, for with the Chinese alphabet there is no advantage in interchangeable types. It was from this, too, that arose the invention of paper in the first century of our era, and the production of inks having a carbon base as with the printers' ink of to-day, and by the same token the first to manufacture lampblack from the burning of oils. It was this that devised the drilling of grain as distinguished from broadcast sowing, a method that saves in the annual seed time of China as much as would feed the inhabitants of Great Britain and Ireland. The primitive Chinese mill for the hulling of rice is substantially the same as the modern mill for decorticating wheat, and another apparatus for the same purpose, a lever armed with a stone at its outer end and actuated at the other by arms radiating from the shaft of a water-wheel, differs in no essential respect from the principle of the trip hammer. What in our day is known as the Belgian System of Canal Propulsion, and now on trial on the Erie Canal, was derived from the Chinese method of crossing rivers. The plan by which life-boats are worked to and fro for the relief of stranded vessels is the same as that by which the ships of Mandarins were drawn against the current of the Yellow River centuries ago. The paddle-wheel was used for purposes of propulsion in China long ages before it revolved in western waters. It was the structure of the Chinese junk that afforded the prototype of the watertight bulkheads used in our modern steamships. Upon rafts or hurdles of bamboo the Chinese spread layers of earth, which they cultivated like garden soil, and thus anticipated by ages the floating gardens of Mexico. In our own country, a factory system of making cheese and butter was initiated about thirty years ago; the like was done by Chinese makers of sugar long centuries before the existence of our continent was known to the eastern world; and the same workers of the cane first used the waste bagasse for heating the evaporating pans. Within the past sixty years, the division of labor has become the distinguishing feature of the industrial systems of Europe and America; the potteries of Kingtze-Chin have practiced the same for many ages, the consecutive labor of fifty different workmen being necessary to the production of a piece of the finest ware. The Chinese terraced the slopes of the mountains with walls of stone for the growth of vegetables, as the shores of Lake Leman are terraced to-day for the cultivation of the vine. Mindful of the chemistry of the soil, they early learned to temper sandy lands with clay, and clay lands with sand; and they carefully gathered and applied all manner of fertilizers, at a time when the wealth of Roman plains was passing through the great Cloacae to the Tiber and the sea. They they were the first to unwind the cocoon of the silkworm, and weave fabrics from its threads. They were the originators of porcelain, and their name, Kao-lin, for the clay of which it is made, has passed into the industrial nomenclature of Europe. They invented gunpowder, not only for fireworks, and for explosive mines in war, but for firearms, for the embrasures of the great wall are fitted for the reception of the swivels of wall pieces, and more than six centuries before the Christian era their cannon bore the inscription, "I hurl death to the traitor and extermination to the rebel." And they discovered, too, in remote times, that the best charcoal is made from willow, a fact recognized by manufacturers of gunpowder in all parts of the world to this day. They burned petroleum in lamps long before such use was dreamed of among Western peoples. They sunk salt wells hundreds of feet through varying strata, and finding that inflammable vapors arose in vast volumes, they led them to the furnaces for use as fuel in heating the factories. They rendered potable the muddy waters of their rivers by treatment with alum, a process employed in Europe with effect for removing clay and other earths from water intended for use in various branches of manufacture. They adopted the decimal system for measures of quantity and weight and value, centuries before French legislators recognized its utility, or French scientists formulated its application to the traffic of Europe; and now, as in the days of the first coinage of copper, the *lee* or *cash*, a disk with a square hole in the center to

permit it to be placed on a string, is the tenth of a *fen*, and the *fen* is the tenth of a *chen*, and a *chen* is the tenth of the value of an ounce of silver.

Their units of volume and length were literally native to the soil, for the one is the cubic contents of a hundred of the grains of the Kow-leang or high millet, the *Holcus Sorghum* of the botanists, and the latter the linear space occupied by a certain number of the same grains, which also afforded a standard of weight. In minor industries they saved the culm and dust of coal, and mingled it with clay and soft earth from the marshes, to form an artifical fuel, an invention currently believed in other countries to be of recent years. They were the first to make spectacle glasses from sections cut from rock crystal. They made cloth from the bark of the nettle—a project revived in Germany, as new, within the past five years—and applied to the extraction of color from a native plant the processes by which indigo is extracted from the Indigofera. They hatched the eggs of fowls by artificial heat, the method by which ostriches are incubated on the ostrich plantations of South Africa. They found food in the roots and the seeds of the lily growing in reedy ponds, and purified the nauseous oil of the palmi christi until it became edible and sweet. They trained the sheep to carry burdens through the highest defiles of neighboring mountains, and taught the brown cormorant to fish in behalf of his owner in the dun canals.

Such were the manifestations of the Chinese intellect as applied to the useful arts. Such were the implements and methods by which the genius of China manifested itself in originating the industries by which her constantly increasing population has been sustained, and which, through almost unnumbered ages, have formed the basis of her power and the foundation of her home and foreign policy. But is to be remarked, and the fact illustrates not only the nature of her people, but the policy of the government, that every art, every implement or method, related only to the furtherance of manual operations. Nowhere is there the slightest evidence of intent to encourage labor saving machinery, which, by dispensing with the labor of some, lessens the cost of the products of labor to all; but everywhere, the ready devising and adoption of whatever furnished employment for human hands, or opened new sources from which the individual could derive food and raiment by personal labor. Within these limits all was devised that was required for use in the agriculture or manufactures of the country. But the limit was early reached, Hence the lack, through many ages past, of industrial advancement, which has given to the arts of China the almost stereotyped character manifest in her social and political institutions. Arts and industries, thus restricted, could only attain excellence through the highest development of mechanical skill, and their rewards could only be obtained through the cultivation of certain faculties, and these not separately, but together, which may be briefly enumerated as accuracy of perception, closeness of calculation, imitativeness in a rare degree, and unwearying patience. The conditions of existence, from the time of the building of the first mud cabins on the banks of the great rivers, has developed these qualities with an intensity not equaled elsewhere in the world. And thus, a symmetry, perfect of its kind, in the nature of the people, has enabled them to excel to the utmost within the narrow boundaries assigned by policy, by usage and tradition. And this excellence, and others of kin to it, which constitute an indefeasible merit, so far as concerns the Chinese in their own country, is a standing menace as an element in the relations of China with the rest of the world.

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS. The last issue of Transactions contains the following papers:

No. 199. Ship Canal Locks to be Operated by Steam, by Ashbel Welch.

" 200. Discussion on the Use of Steel for Bridges, by William Sellers.

" 201. Remarks on the Causes of Fall of the Arched Approach to the South Street Bridge, Philadelphia, by J. G. Barnard.

" 202. Note on Kutter's Diagram, by Chas. H. Swan.

IRON AND STEEL NOTES.

WELDING IRON AND STEEL.—German engineers are now discussing eagerly a question which has seriously engaged attention in this country, and though nothing conclusive has been reached abroad, it will be profitable to review briefly the conflicting opinions offered, based upon experience, and in some case upon experiments of a specific character. The last German engineer to take up the subject is Herr C. Petersen, of Eschweiler, from whose paper, read before an association of railroad engineers, we glean the following: "The welding of iron is dependent upon its property to assume a pasty state within a certain range of temperature, and it may be stated, in a general way, that the facility with which the welding may be performed is dependent upon the duration of this peculiar condition. Leaving out of consideration other circumstances affecting welding, it is conceded by the majority of metallurgists that an increase in the percentage of carbon in the iron impairs the property of welding, and it is generally believed that when two per cent. is reached it ceases entirely. It might be concluded that, therefore, it is desirable to keep the carbon within the lowest limits attainable, but there is some diversity of opinion on this point, because a second important condition for good welding comes into play. It is necessary, in order to unite two pieces of iron, to make the surfaces to be welded free from any coating of oxide, a matter which is generally reached by fluxing the oxide by means of sand, borax, &c.; and some hold that a certain percentage of carbon is necessary in order to afford material for the reduction of this oxide. Wedding, among others, maintains that such is not the case, and that the silicate of iron contained in wrought iron plays an important *rôle*. These theoretical considerations have quite recently become of considerable interest, because they may offer a clue to detecting the reason why the steel produced by the open-hearth and Bessemer processess is generally inferior as regards welding power to wrought iron, an inferiority which stands in the way of the more general adoption of steel in place of wrought iron. The former, it is true, can be welded, but there are many practical difficulties. Certainly steel-headed rails show a case of good welding, and tires, tubes, &c., have been made of Bessemer steel on a large scale, but still steel cannot compare in this respect with wrought iron. It is said that hot working in the Bessemer converter or open-hearth steel furnace favorably affects the welding power, and this is explained by pointing to the fact that hot steel will contain a smaller amount of oxides mechanically mixed than that produced at lower temperatures. Herr Petersen claims that silicon is injurious, while Herr Koehler, of Bonn, during the discussion following the reading of the paper, held that it was not alone not injurious, but actually favorable for good welding. Herr Helmuth took a different view, and stated that at Bochum, during a series of experiments in an open-hearth furnace, they tried keeping the silicon low, but reached no results, and were similarly unsuccessful by increasing the percentage of phosphorous. They then turned to the Bessemer process and commenced over-blowing, which improved the welding, though not in a sufficient degree. By using oxides of iron, however, they obtained much better results, but they did not follow out the matter, because they found that pieces welded together had a yellow red fracture near the weld, and Herr Gresser, of Grafenburg, added that the same tendency to red-shortness was observed by them when making a weldable material in the open-hearth furnace. In using the Terrenoire alloy they found that a good product was obtained by adding about four times as much manganese as silicon. It was, however, abandoned on account of its high price. Herr Petersen concludes by giving some interesting data in regard to the influence of arsenic upon the welding of iron. A lot of inch rod was rejected on account of difficulty in welding, and it was found that the heated rods had a fatty lustre, and that two rods laid one upon another slid off as though the surfaces were polished. This took place, although the balls in the puddling furnaces and the piles welded well. The cause of this anomaly was found to be that the injurious effect of the arsenic comes out strongly only after the carbon has been considerably reduced. The following analyses are given as representing the composition of the pig used in making these rods, the first being white, the second gray pig:

Sulphur	0.774	1.843
Phosphorus.....	trace	trace
Copper	0.090	0.580
Arsenic.....	4.250	5.980
Antimony	1.145	1.068

STEEL IN CHINA.—The steel manufacture has assumed a considerable importance in China, especially along the upper Yangtze, from which district the metal is shipped to Tien-Tsin, The price obtained for the steel in China is higher than is secured by that imported from Sweden. Chinese metallurgists recognize three different qualities of steel. The first of these is produced by mixing crude iron with wrought iron and submitting the mass to the action of fire; the second, by the repeated heating of pure iron; while the third consists of the native steel, which is produced in the south-western districts. The different names by which these various kinds of steel are known are the following: The "twan-kang," or ball steel, on account of its globular form; the "wan kang," or tempered steel; and the "wee tei," or false steel. The Chinese seem to have been acquainted with the manufacture and use of steel from the earliest times; and at the epoch of the Han dynasty, iron masters were appointed in the different districts of the ancient Leangchow, whose duty it was to superintend the iron manufacture.

DEFLECTION OF IRON AND STEEL RAILS.—In the *Comptes Rendus* of the Paris Society of Civil Engineers is a paper by M. Tresca, giving the results of some experiments on the deflection of iron and steel rails between the limits of elasticity and rupture. They show

that, for these two metals of ordinary commercial character, the co-efficient of elasticity is nearly the same, thus confirming certain special experiments in 1857 and 1859 upon Swedish iron and cementation steel made from such iron. M. Tresca finds that the limit of elasticity for a given bar may be extended in proportion to the strain to which it had been previously submitted, and that the elastic limit may be pushed almost to the point of rupture without the co-efficient of elasticity having varied in any perceptible degree. The metal, when it comes from the work-shops, is in a state of instability, which disappears only by use; it becomes, by means of the actions to which it is successively submitted in its employment, more homogeneous and more elastic, but at the same time a little more flexible.

RUSSIAN TOOL STEEL.—The tool steel used in Russia is imported chiefly from England, although some private firms are using German steel. The Obouchoff Steel Works, near St. Petersburg, are, however, making tool steel for their own use, and are also filling some orders for other Russian works. At the Obouchoff Works, Whitworth's system of compressing fluid steel has been for some time employed, and it is now being turned to account for the production of solid ingots of tool steel. The steel is prepared in crucibles from a mixture of blister steel with refined cast iron and ferro-manganese, the materials employed being very pure. The Oural blister steel used contains carbon 1 per cent., silicon 0.06 per cent., manganese 0.22 per cent., and phosphorus 0.07 per cent. The application of the Whitworth system of compression enables perfectly sound ingots to be obtained, the whole of each ingot being available for the production of tool steel by the further processes of hammering and rolling.

RAILWAY NOTES.

STARTING upon the basis that there are more than 10,0000,000 car-wheels in use on the railways of the United States, that the average life of a wheel is eight years, and that it requires a little over a ton of pig iron to make four wheels, an American contemporary concludes that there are required 1,250,000 new wheels to replace those worn out each year, and to make these over 312,500 tons of pig iron are required. As 1,250,000 wheels are worn out each year, and as the average weight of a worn-out wheel is about 515 lbs., something like 287,389 tons of this old material are available for re-manufacture, The difference between this sum and 312,500—the approximate weight of the new wheels—shows the weight of new material consumed per year in the manufacture of car-wheels, assuming that all the old wheels are manufactured into new ones. Manufacturers guarantee wheels to run from 50,000 to 60,000 miles, but they not unfrequently greatly exceed this.

ON a down grade of 1 in 38 on the Aachen Railroad, in Germany, the amount of rail wear per 1,000,000 kilo-metric tons (of 2,205 lbs.) gross weight was 3.059 in., so that a rail was completely worn out in five years. On August 10, 1878, as an experiment, cast steel blocks were substituted for the wrought iron ones on the left side. On taking measurements, May 6, 1879, it was found that the left rail was worn down 0.287 in., the right rail 0.35 in., while formerly the rail on the right side was least worn. For the sake of obtaining a certain result, the brake blocks were exchanged right with left, on the 6th of June, and the height of the rail (twenty lengths on each side of the track) carefully measured. According to the measurements made on September 18 and November 24, 1879, the wear on the steel brake-block side amounted to 0 5 in., on the side where the wrought iron blocks were used, 0.086 in. per million tons gross load. On a down grade of 1 in 75, between Heissen and Mülheim, the rail wear, with a gross load of 34 million tons, amounted to 0.507 in. in eight years. The chief engineer of the road can only attribute the enormous amount of wear to the fact that the soft wrought iron blocks hold the wheels perfectly tight, while the hard steel has not such a grip on them, they occasionally slip round, and less friction results to the track.

SPEAKING of the railway across Newfoundland to which the Colonial Legislature has committed itself, the *Colonies and India* says: Starting at St. John's the line will take a south-westerly course for 30 miles, and, gradually bending to the north-west and west, will pass along the narrow neck of land which separates Trinity Bay from Placentia Bay. Hence it passes in a general westerly course to St. George's Bay on the west coast. The country to be opened up by this railway is well watered and well wooded, resembling the general features of the Cumberland Lake District. The highest land traversed is 1,100 feet above the sea, and the total length of line will be about 350 miles, the distance in a direct line being 275 miles. Much of the country has hardly been visited by white men, and it is described as affording rich pasture land. The district of the western terminus, St. George's Bay, is one of the healthiest districts in the world, free from fogs and from the occasional severity of the weather felt in other parts of the island. It is hoped that eventually, communication, by means of ferry steamers, will take place between St. George's Bay and the mainland, thus enabling passengers and goods to be carried without change of train from St John's to any part of the Dominion of Canada, and saving about 1,0.0 miles of sea voyage.

ONE of the subjects reported upon at the technical convention of the German Railroad Union in 1878 was the lighting of cars. Reports were asked from the several companies with regard to the improvements effected in the illumination of passenger cars, particularly with gas, and the cost of applying, keeping in order, and running the different systems. Forty-five reports were rendered. Six corporations, representing 17.7 per cent. of the passenger coaches owned by the roads reporting, used gas, chiefly prepared on the Pintsch system; in one instance no other form of lights was used on the road, and all expressed satisfaction and an in-

tention to extend its use on account of the cleanliness, saving of labor, and superiority of lighting power. Five roads employed stearine candles in closed lamps, and 44.8 per cent. of the cars are lighted by oil lamps, the majority burning the commonest vegetable oil with Argand burners in the first and second class carriages, and common flat wicks in the lower classes. Some of them employed lamps with the oil reservoir above the flame to prevent the oil getting too thick to burn in cold weather; the supply of oil carried is sufficient for a ten hours' journey. On three roads American mineral oil was used in closed lamps with much better effect.

ENGINEERING STRUCTURES.

LONDON WATER SUPPLY.—The following proposal to supply the metropolis with water from Bala Lake, in North Wales, has been submitted to the Secretary of State for the Home Department, by Mr. J. W. Welborne, for consideration by the Committee of the House of Commons now sitting:

"The water of Bala Lake has been carefully tested and proved to be equal in purity to the water of Loch Katrine, and ample in quantity for the supply of the metropolis. It is also probably sufficient for the towns *en route*. The country adjacent is sparsely populated, and a few mountain sheep and grouse constitute the occupants of the surrounding hills, hence there is a minimum of possible pollution. The rainfall registered at Bala for the year 1876, was 52.69 inches which is about the average rainfall there. The lake is nearly four miles long, by three-quarters of a mile wide, covering 1,100 acres. The water-shed of the district contains 35,392 acres, or 55 square miles, this, with the Bala register of rainfall would, after deducting 10 per cent. for absorption, give 37,040,000,000 gallons per year, or 104,000,000 per day. But inasmuch as Bala lies on a level with the lake, the register of the rainfall there does not represent the rainfall of the district. On the surrounding mountains the rainfall is probably twice as much as in the valley, which will leave a large surplus for supply, after giving compensation to the river.

"The lake is 553 feet above Trinity high mark, and 300 feet above Stanmore, where it is proposed to make the reservoirs. By embanking the lake 5 feet, and drawing down 2 feet below the present level, sufficient water can be impounded to supply 104,000,000 gallons daily, for thirty seven days without any rainfall. Should further supply be required 50,000,000 gallons per day can be obtained from the River Vyrnwy which is situated on the lines of route to the metropolis.

"It is proposed to convey the water from Bala through a series of iron pipes sunk to a depth sufficient to protect them from the action of the frost, along the sidings of the Great Western Railway to Stanmore, where the reservoirs should be on a scale adapted to provide for a storage of water equal to forty days' supply. These should consist of one or more large reservoirs and ten smaller ones. The large reservoirs would be capable of holding three thousand million gallons, or 30 days' supply, and would be lined with brick or stone The ten smaller ones, lined with white glazed brick, would each be calculated to contain 100 million gallons. The space required for those reservoirs would be 500 to 600 acres, for the large ones according to depth, and 25 acres for each of the smaller ones. The water would be delivered into the large reservoirs as pure as its source, thence it would pass through a system of filtration of approved character into the smaller reservoirs in a condition of absolute purity. These reservoirs being 250 feet above the Bank of England, the water on reaching London would be conveyed through the existing mains of the water companies at high service level.

"*General Remarks*.—Had Bala Lake existed at Stanmore, instead of North Wales, it would, doubtless, long ago have formed the source of the London water supply. If it is approved as a source of supply, it is simply an engineering question how to convey the water for the use of the metropolis free from pollution in the most effectual and economical way. By adopting the sidings of the Great Western Railway as the route, the following advantages would be obtained:

"1. The right of way for almost the entire route would be secured by one negotiation.

"2. Land otherwise of no value would be utilized without detriment either to it or to the property of the railway company.

"3. All the plant required would be delivered by the railway company at the places where it would be laid.

"4. The telegraph system would be available in case of any accident to the pipes.

"5. There would be great saving in the time required for the construction, and also great saving in the cost.

"By making the reservoirs at Stanmore a sufficient level would be obtained to supply the high service to London without pumping, the cost of which, at present, with filtration, is about £100,000 (one hundred thousand pounds) per annum. By the use of white glazed bricks for the lining of the smaller reservoirs, facilities for quickly and thoroughly cleansing them would be obtained. In short, pure water would be delivered from them as from a china basin."

RUSSIAN SURVEYS IN THE BALKAN PENINSULA.—The geodetic and astronomical operations carried on by the Russians in the Balkan Peninsula, which in 1877 and 1878 covered the central part of Bulgaria and Roumelia, were, in 1879, extended eastward as far as the sea, and west over the Rhodope mountains as well as along the new Serbo-Turkish frontier to Novi-Bazar. A trigonometrical network thus now covers Bulgaria and Roumelia as well as a part of the Turkish territory. On the Serbo-Turkish frontier a strip 30 versts broad, and from the Bulgarian boundary to Novi-Bazar 175 square versts long, has been triangulated. Over 150,000 square versts, 1,300 points, have been fixed as sure bases for a special topographical map of Bulgaria, Roumelia, and Turkey from San Stefano in the south upwards. The geodetic network is connected both with the

Russian meridian measurements and the Austrian Survey. The calculations are not yet completed for all points, yet the leader of the operations, Colonel Lebedew, has put together a relief of the Great Balkan from the sea to the Servian boundary, and the Little Balkan, with its off-shoots, to the valley of the Maritza. From this it is seen that the crest of the Balkan, from the Black Sea to Kotel, is nowhere more than 3,000 feet above the sea level; from Kotel to the meridian of Selwi it rises from 3,500 feet to 4,900 feet; further to Zlatitza it has nearly everywhere a height of from 5,600 feet to 6,300 feet, its highest point rising to 7,000 feet; the last section, from Zlatitza to the Servian frontier, has a height of from 4,900 feet to 6,300 feet, without any very prominent summit. The highest point of the Balkans, the Jümrüktschal, 7,830 feet high, lies 12 versts north of Karlovo (1,260 feet above sea level). The Rhodope mountains are mostly 5,600 feet above the sea, the highest point not exceeding 7,000 feet. The Rilo mountains exceed the Balkans in height, their three highest points, Oleni Wrch, Popowa Schapka, and Segmentski Wrch, rising to more than 8,400 feet above the sea. Mount Witosch, isolated over the plain of Sofia, rises over 7,000 feet, and stands only second to Jümrüktschal in the Balkans. In general, the surface of the Balkan Peninsula rises in the direction from the Black Sea towards the west very considerably, so that *e. g.*, the valley of the Isker at Samakow, 3,360 feet high, lies higher than the crest of the Balkans between the Black Sea and Kotel. To the network of telegraph observed places have been added in 1879 over 20 astronomically observed points, so situated that they form, with the fixed points of 1877 and 1878, four circles, which establish a reciprocal control over the operations. In Servia, the position of Nisch has been ascertained, and will connect the operations with those of the Russians by means of the difference of longitude between Rustchuk and Kishinew. This year Colonel Lebedew will further ascertain the difference between Kishinew and Rostov, on the Don. On the topographical operations from 1877 to November, 1879, 100 topographers, divided into two main parties were engaged. One, under Colonel Shdanow, completed in 1878-79 the east part of Bulgaria and Eastern Roumelia, 14,700 square versts; the other, under General Ernefeld, from 1877 to 1879, completed 82,350 square versts in these difficult western part and on Turkish territory in the Midia-Adrianople-Dedeagatch section. Along the boundary between Bulgaria, East Roumelia, Servia, and Turkey, a strip ten versts wide was measured in 1879. These boundaries run mostly at considerable heights (over 5,000 feet) from summit to summit, along the water-parting and mountain crest. The plates of the survey in Eastern Bulgaria were ready to be laid before the Russian Emperor on April 19; the sheets of West Bulgaria will be ready in November next. The maps will afterwards be published in heliography.—*The Times.*

THE BALTIC AND GERMAN OCEAN CANAL.—The project for this canal, which has during the last thirty years been more or less under consideration, has lately received a new impulse through an interesting pamphlet published by Mr. Dahlström, who points out the great advantage of a canal connecting these two seas, and as the most suitable location the line between the Bay of Kiel, on the Baltic, and the town of Brunsbüttel, on the German Ocean, is recommended. The canal would have a width at water level of 164 feet, at bottom of 65 6 feet, and a depth of 21 feet 4 inches, but by a special arrangement of locks the depth could be temporarily increased to 24 feet 6 inches, which would allow the largest vessels afloat to pass the canal. These dimensions are but little below those of the general section of the Suez Canal, which is 110 feet wide at water level, 72 feet at bottom, while the depth varies from 24 feet to 26 feet. By reducing the dimensions to the figures quoted above, Mr. Dahlström calculates that the cost of the canal may be reduced by about £750,000 as compared to previous estimates, and puts the total expenditure at £3,750,000. Of this sum it is proposed that the Government provide one-fifth, while the remainder is contributed by private enterprise. The number of ships now passing the Sound, between the island of Zealand and Sweden, amounts, according to Mr. Dahlström, to 36,670 per annum; of these 9,100 are steamers, and if only two-thirds, or say 24,500 of the vessels will use the new canal, which for steamers effects a saving over the old route of thirty hours, and for sailing vessels of four days, a small tax per ton will pay a good interest on the invested capital. The preliminary works for this canal are making good progress under Mr. Dahlström's direction. Borings along the route of the proposed canal are completed, and are said to have given very satisfactory results, while the surveying operations are expected to be completed during this autumn, when plans and specifications will be prepared, and submitted for Government approval.

ORDNANCE AND NAVAL.

VELOCITY OF PROJECTILES IN GUNS.—The methods that have been tried for ascertaining the law of motion of a projectile in the bore of a gun (with a view to finding the law of pressures developed) give only a small number of points of the curve of spaces traversed in given times, and they involve perforation or other injury to the walls of the gun, so that they are applicable only to large pieces. A new and ingenious method, advantageous in these respects, has been contrived by M. Seibert. In the axis of a cylindrical hollow projectile he fixes a metallic rod of square section, which serves as guide to a movable mass. This mass, or runner, carries a small tuning-fork, the prongs of which terminate in two small metallic feathers, which make undulatory traces on one of the faces of the rod (blackened for this purpose with smoke) as the runner is displaced along the rod. The runner, it will be understood, is situated at first in the front part of the projectile, and while the latter is driven for-

ward remains in place, the rod of the projectile moving through it. The escape of a small wedge between the prongs of the fork at the moment of commencing motion sets the fork in vibration. It can be easily shown that, owing to the very high speed imparted to the projectile, the displacement in space of the inert mass, through friction and passive resistances, which tend to carry it forward with the projectile, is such as may be quite neglected. So that the relative motion of the mass recorded by the tuning-fork may be considered exactly equal and opposite to the motion of the projectile. A study of the curves produced guide to the laws of the motion and of the pressures developed by the charge. Evidently the motion of a projectile as it buries itself in sand or other resistant medium may be similarly determined.

THE BOILERS OF THE LIVADIA.—Those engineers who hold that steel is not a good material of which to make boilers, will find support for their opinions in the failure of the boilers of the Czar's yacht Livadia. This vessel was to have had eight main boilers of steel Six of these were finished and ready for the hydraulic test of 150 lb. per square inch. On the pump being set to work the first boiler split through the solid steel plate, the longitudinal crack being about 3 feet long, the pressure reached being 140 lb. The whole of the boilers were, we understand, thereupon condemned. It was determined, however, to proceed with the test, and three more boilers were easily burst with pressures varying, we are told, between 80 lb. and 140 lb. The plates were of Cammel's steel. This experiment will go far to cause the total rejection of steel by shipowners as a material for boilers. It is also stated that experiences recently acquired are all against steel as regards the durability of furnace plates; and some eminent marine engine builders will not employ it on any terms. So far nothing more is known concerning the break-down of the Livadia's boilers than the broad facts as stated above, but the subject is so important that it is to be hoped Messrs. John Elder & Company will supply full information on the subject.

EXPERIMENTS IN SHIP-BUILDING. THE LINES AND THE SPEED OF THE "LIVADIA."—All persons interested in naval architecture will watch, with some curiosity, for the details of the actual performances of the Livadia, the anomalous raft-palace recently built for the Czar, in the Fairfield Yard at Govan, on the Clyde, and launched on the 7th of July. The Livadia is the latest modification of the famous circular, or rather soup plate shaped, craft invented by the Russian Admiral Popoff. It consists, in fact, of a sort of raft, in the form of a turtle, or, as the designer, Captain Goulæff, prefers to call it, a turbot, with a palace on its back. The daily papers have given such full details of this yacht — the *Times* having even produced a kind of diagram representing it—that it is unnecessary to reproduce them here. But it is desirable to call attention to those main principles of structure as to which the Russian naval architect entirely ignores all rules consistent with the best results of experiments like those made for our Admiralty by Mr. Froude, to say nothing of the long labors of Mr. Reed and Mr. Scott Russell. The "wave-line theory" is altogether ignored by the builders of the Livadia. The possibility of floating over waters liable to stormy disturbances, without offending a squeamish stomach, has been the great point at which Captain Goulaeff aimed. The experience of the Great Britain, the Great Western, and the Great Eastern, has shown that great steadiness, as regards the pitching motion of a ship, may be attained by making the keel long enough to ride on the crests of two or three waves at a time. It may be taken as a corollary of this proposition, that if the bottom of a craft be made wide enough, immunity from rolling may be attained in the same way. The only drawback to this theory is, that the proportions which tend to give a lateral stability are incompatible with speed; at all events, without the incurring of an enormous expense. It will be seen at a glance that the Russian naval architect is not ignorant of this fact. The length of the Livadia is 230 ft., while what may, in courtesy, be called its beam, is 153 ft. The displacement is calculated at 4,000 tons, spread over an oval area of 14,500 square feet. The proportions of the length and beam of modern ocean steamers range from 6.38 to 1, to 10.61 to 1; and the resistance to the passage of a ship through the sea is taken, by the usual rule adopted by the French naval architects, as proportionate to the area of the midship section, multiplied by the cube of the velocity. The English rough rule gives two-thirds of the displacement, multiplied by the cube of the velocity. The velocity which the Livadia is expected to attain is stated at fourteen knots an hour. That of our recent war ships is eighteen knots an hour; and the speed attained by an Indian dispatch boat for the Orissa canals, built by Thornycroft, of London, has been minuted at 24.61 miles per hour. As resistance is now regarded, we have the practical rule, that the indicated horse-power employed in a steamer is proportionate to the cube of her speed. The cube of 18 is more than double the cube of 14 (being respectively 5,832 and 2,744; so that the resistance overcome by the Livadia, in proportion to its midship section, is less than half that overcome by such an English man-of war as the Iris, as far as is due to the speed maintained. But the horse-power provided per ton is more than three-fold in the case of the Livadia. The indicated horse-power proper to give the speed of fourteen knots an hour to a vessel of this length and beam, taking the draught of water as 6 ft. according to the practical formula given by Mr. William Allan, in his "Shipowner's and Engineer's Guide," is under 8,000 h.p That provided by Captain Goulaieff is 10,500 h.p. The first is 2 h.p. per ton of displacement. The second is 2.625 h.p. per ton of displacement. The proportion in the English war ships may be taken at seven-eighths of a horse power per ton of displacement. Thus for a speed which gives less than half the resistance overcome by such vessels as the Iris, more than three times the indicated horse-power per ton is provided. In other words, the cost of

fuel for the steam propulsion of the Livadia will be more than six times as much as that required for a vessel of normal proportions.

The calculations given of the displacement of the Livadia do not come out quite exact. If a weight of 4,000 tons is distributed over an area of 14,500 feet, there will be 3.625 square feet of surface per ton; and taking the weight of water at 62 lbs. per cubic foot, we require 10 ft., instead of 5 ft., of immersion to balance the weight of the vessel. But the screws are said to draw 16 feet of water, or 10 ft. more than the intended draught of the vessel. There is good reason to suppose that such a disposition will naturally diminish the speed of the craft, as in the case of towing a rope through the water.

Nor is this the only point to be regretted as to the arrangements for propulsion. The battle between floatation and engine-power is one as to which, by the use of steel, and the constant improvements in engines, the advantage is tending to the side of the latter. In an enormous flat-bottomed craft, if in anything, it might be hoped that so much power might be placed as to produce the known, but not thoroughly understood phenomenon, of the rise of the vessel, and its skating or sliding over the surface of the water—as a canal-boat will do if tugged at a great speed. We can conceive such a result to have been possible in the case of the Livadia, if the efforts of the engineer had been directed to produce it. We should anticipate that the deep submersion of the screws will be fatal to such a hope. Any way, we shall look with interest to the test of actual navigation, and shall be very glad to hear of any result of use to the shipbuilder from the construction of this abnormal floating palace.—*The Builder.*

BOOK NOTICES

PUBLICATIONS RECEIVED.

THROUGH the kindness of Mr. James Forrest, Secretary of the Institution of Civil Engineers, we have received the following selected Papers :

"The Temnograph," by Alexander Manson Rymer-Jones, A. M. I. C. E. "The Chile Vein Gold Works, S. A.," by George Attwood, F. G. S. "A New Snow Plough," by John Newman, A. M. I. C. E. "Rural Water Supply," by Thomas Sullock Stooke, A. M. I. C. E. "The Calder Viaduct," by David Munro Westland, M. I. C. E. "The Hydrogeology of the Lower Greensands of Surrey and Hampshire," by Joseph Lucas, F. G. S. "Removal of Sunken Rocks in Brest Harbor," by H. Willotte. "Abstracts," Vol. LXI., Part 3. "Bulletin of the American Geographical Society," No. 4, 1879. "National Quarterly Review," July. "Journal of the United States Association of Charcoal Iron Workers."

TRAITE ELEMENTAIRE DE LA PILE ELECTRIQUE. Par ALFRED NIAUDET. Paris: J. Baudry. For sale by D. Van Nostrand. Price $2 00.

This is a second edition of a work pretty well known. The work treats first of the construction of a great many kinds of batteries, and of the chemical sources of the electro-motive energy in each kind.

The peculiarities of the leading varities, together with a special statement regarding the kind of service each is best fitted for, is a valuable feature of the treatise.

Tables of the resistances of battery solutions, and of the electro-motive force of batteries are given at the end of the volume.

Sixty-five excellent wood cuts embellish the text.

MANUAL OF HYDRAULIC MINING FOR THE USE OF THE PRACTICAL MINER. By T. F. WAGENER, E. M. New York: D. Van Nostrand. Price $1 00.

This is a book for the pocket, and contains only such practical knowledge as is of constant service in the field.

The contents embrace: General Physical Conditions, General Methods of Placer Mining, Directions for the Miner, the Properties of Water, Construction of Water-Ways, Flow of Water in Flumes and Ditches, Iron Piping, Nozzles and Discharge, the Sluice.

The methods of applying the rules for computation are illustrated with exceeding fullness by examples worked out.

ON THE MECHANICAL EQUIVALENT OF HEAT. By HENRY A. ROWLAND. Cambridge University Press.

This work is a collection of the author's papers reprinted from "The Proceedings of the American Academy of Arts and Sciences." Besides the essay named in the leading title of the book, two others are also given: The Variations of the Mercurial from the Air Thermometer, and The Variation of the Specific Heat of Water.

The essays are of the greatest value to students of physics, not only from the presentation of the facts, but chiefly because they exhibit the method of an eminent worker, both in his way of experimenting, and also in his way of deducing the laws from the observed phenomena.

AN ELMENTARY TREATISE ON THE DIFFERENTIAL AND INTEGRAL CALCULUS. By EDWARD A. BOWSER, Professor of Mathematics and Engineering in Rutger's College. New York: D. Van Nostrand. Price $2 25.

The flattering reception accorded to Prof. Bowser's Analytical Geometry, would seem to justify the expectation of an equally ready acceptance of this later book.

The merit acknowledged in the former book, of a clear logical presentation of the science as recently developed, and divested of the portions not serviceable to the learner, is certainly a characteristic of the last work of this author.

Teachers and students who have found their wants served by the first book, will, we are confident, welcome the calculus as a fitting supplement.

The two branches of the calculus are presented complete in a 12mo of 395 pages.

Contents: Part 1—Differential Calculus—1. First Principles; 2. Differentiation of Algebraic and Transcendental Functions; 3. Limits

—Derived Functions; 4. Successive Differentials and Derivatives; 5. Development of Functions; 6. Evaluation of Indeterminate Forms; 7. Functions of two or more Variables, and Change of the Independent Variable; 8. Maxima and Minima of Functions of a Single Variable; 9. Tangents, Normals and Asymptotes; 10. Direction of Curvature—Singular Points—Tracing of Curves; 11. Radius of Curvature—Evolutes and Involutes—Envelopes.

Part II.—Integral Calculus—1. Elementary Forms of Integration; 2. Integrations of Rational Fractions; 3. Integration of Irrational Fractions by Rationalization; 4. Integration by Successive Reduction; 5. Integration by Sines—Successive Integration—Integration of Functions of two Variables and Definite Integrals; 6. Length of Curves; 7. Areas of Plane Curves; 8. Areas of Curved Surfaces; 9. Volumes of Solids.

MISCELLANEOUS

AN INTENSIFIED ELECTRO-MAGNET.—Dr. Stone recently exhibited before the Physical Society a very interesting electro-magnet of novel construction, and based on a principle which will probably be applied with advantage in the construction of electro magnets for dynamo electric machines and telegraphic apparatus. It is known that electro-magnets enclosed in jackets of soft iron, are far more powerful than when the copper wire of the coil is unenclosed. In fact, the iron jacket, like the second armature or diaphragm in M. Ader's form of Bell telephone recently described by us, has the effect of exalting the magnetic power of the poles. Dr. Stone does not employ a soft iron jacket; but, instead of using copper wire to wind the bobbins, he uses best charcoal-annealed iron wire about $\frac{1}{8}$ in. in diameter. Four wires are wound on in parallel circuits, and the current is split up among them in "multiple arc." They are insulated from each other by paraffine wax. By this felicitous arrangement the lifting power of Dr. Stone's large magnet is, with a battery of five or six Bunsen cells, increased fourfold.

IN continuing his researches on the welding of solid bodies by pressure, M. Spring has subjected to various strong pressures—up to 10,000 atm.—more than eighty solid pulverized bodies; this, according to *Nature*, was done in vacuo, and in some cases at various temperatures. The results are highly interesting. All the crystalline bodies proved capable of welding, and in the case of bodies accidently amorphous the compressed block showed crystalline fracture; crystallization had been brought about by pressure. Softness favors the approximation of the particles and their orientation in the direction of the crystalline axes. The amorphous bodies, properly so called, fall into two groups, one of substances like wax—*ciroid* bodies—which weld easily, the other of substances like amorphous carbon—*aciroid* bodies—which do not weld. The general result is that the crystalline state favors the union of solid bodies, but the amorphous state does not always hinder it. M. Spring says the facts described do not essentially differ from those observed when two drops of a liquid meet and unite. Hardness is a relative, and one may even say subjective, term. Water may appear with a certain hardness to some insects, and if our bodies had a certain weight we should find the pavement too soft to bear us. Again, prismatic sulphur is changed by compression to octahedric sulphur; amorphous phosphorus seems to be changed to metallic; other amorphous bodies change their state, and mixtures of bodies react chemically if the specific volume of the product of the reaction is smaller than the sum of specific volumes of the reacting bodies. In all cases the body is changed into a denser variety, whence may be inferred that the state taken by matter is in relation to the volume it is obliged to occupy under action of external forces. This is merely the generalization of a well-known fact. Some curious results are deduced from it. The researches described have important bearings on mineralogy and geology.

MESSRS. SIEMENS & HALSKE have, it is said, laid before the municipality of Berlin another project for the establishment of electric railways in that town. They propose that all the railway termini in Berlin, and the stations of the metropolitan railway, should be placed in communication by the electrical railway It is proposed also that a line should be constructed from the Skalitzerstrasse to the terminus of the metropolitan railway and to the Zoological Gardens, passing by the stations of Potsdam and Anhalt, and that a second line should be laid between the Brandenburg Gate and Charlottenburg.

THE explosive disintegration of toughened glass tumblers forms the subject of further correspondence in *Nature*. Mr. T. B. Sprague writes that a member of his family was about to take a seidlitz powder, and had poured the contents of the blue paper into a tumbler of toughened glass half filled with cold water, and was stirring it gently to make the powder dissolve, when the tumbler flew into pieces with a sharp report. The bottom of the tumbler was not altogether fractured, but cracked into a number of little squares, which could be separated readily. Another correspondent says: "In a hot room I had just finished what is usually called a 'lemon squash,' *i. e.*, the juice of a lemon and a little white sugar, with a bottle of soda water, a lump of ice being put into the mixture. I was talking at the time, and so held the empty glass with a spoon in it in my hand for a second or two, when it suddenly went off in my hand into thousands of pieces, none larger than an inch or so. I picked up one of the largest and thickest pieces, and found it to be so thoroughly disintegrated that I broke it up with my fingers into about a hundred small pieces, and might have done more."